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ACQUISITION OF STUDY REPORTS FOR LITERATURE REVIEW OF HORIZONTAL WELLS AND MODELS FOR HORIZONTAL WELL INJECTORS AND PRODUCERS.

[Part of Energy, Mines and Resources Cost-Shared Energy Conversion Program and part of the Federal Panel on Energy P&D (PERD)]

Work on the project was conducted under the auspices of the Canada Center for Mineral and Energy Technology CANMET; Energy, Mines and Resources Canada.

Contract File No.: 23440-8-9231/02-SQ

CANMENT SCIENTIFIC AUTHORITY: Dr. A.E. George

DATE: April 1991

426 pp

PART 6

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91-06121/

EXHIBIT III

COPIES OF THE PATENTS CITED IN THE REPORT

VOLUME 1

Year 1976-1983

BEFORE - 1976

007527

PATENT OFFICE

APPLICATION FOR PATENT

PATENT NO.	245317
DATE	DEC 16 1924
NO.	271926 ✓
FILED	Nov 10/14, 1922

FEES RECEIVED		ASSIGNMENTS RECORDED	APPLICANT	ATTORNEY
245664	AUST. FEE (1) $	—	William Georgeson	Lougheed, McLaws, Sinclair & Redman, 22 Eighth ave. West, Calgary, Alta
	(2)			
	(3)			
	(4)			

COST OF COPIES		CARDBOARD DRAWINGS	INVENTION
	PETITION .....$	6 D.D.	Methods for the Extraction of Bitumen and Other Substances from Natural Deposits of Tar Sands
1.00	OATH		
.25	CORRES., ETC.		

READY FOR ISSUE

JUN 3 1924

NOTICE OF ALLOWANCE

PATENT MAILED

DEC 16 1924 + Bal. fee 20.00

to A. H. Hinds

ALLOWANCE D JUN 3 - 1924

ACTION

Acknowledged by Circular I, and receipt mailed Nov. 16 1922. & $5.00 sta. Let recd Nov. 21/25/22. Amd Dec. 1/22. Ack'd by Cir [illegible] Dec 7 [illegible] Let & Oath recd Dec 15/19/22 Ack by Cir 6 Dec 21/22 [illegible] mld Feb 16/23 Let & dupl. recd (sandt) May 9/14/23. Ack by Cir 6 May 16/23 [illegible] mld May 21/23 Let, Pet, P of A, Oath and specs, clo, tracgs & B.D. recd Sept. 15/19/23. Ack by Cir 6 Sept 22/23 [illegible] & Dupl. mld Oct. 8/23 Let recd Oct. 12/17/23 [illegible] Let recd Dec 18/24/23 N. D. Ack by [illegible] called for Jan 4/24 Letter & dup. recd Mar. 10/14/24 Ack Mar. 22/24 [illegible] mld Apr. 12/24 Let dupl. [illegible] May 19 Ack May 23/24 [illegible] 20.00 [illegible] Oct 20/24 [illegible] Oct 21/24 [illegible]

ASSISTANT COMMISSIONER

INFORMATION CENTRE

TO ALL WHOM IT MAY CONCERN :

Be it known that I, William Georgeson, of the City of Calgary, in the Province of Alberta, manufacturer, have invented a certain new and useful Process for the separation and extraction of bitumen and other substances from natural deposits of bituminous sands, of which the following is a specification :

The accompanying drawing illustrates the apparatus and method used in this said process, in which Fig. 1 is a vertical section of bituminous sands showing an entrance made from the side and Fig. 2 is a vertical section of bituminous sands showing an entrance made from above. These figures are merely explanatory and do not limit the application of the process, which, as hereinafter evident, may be varied to suit local conditions.

Similar letters refer to similar parts throughout the several views.

A is the overburden, B is the bituminous sands and C is the bed rock, commonly limestone. In Fig. 1 an entry or tunnel D is driven in from the side and carries a steam pipe E from boiler G, which has a super heating attachment whereby the steam may be heated above 100 degrees Centigrade. A pipe (or pipes) H of comparatively large diameter and having holes bored in its lower extremity as shown in Figs. 1 and 2, is sunk into the sands B through the overburden A for the purpose of removing the liquids I formed by the action hereinafter described. In certain cases, depending upon local conditions, this pipe (or pipes) H may be dispensed with and the liquids I removed as the entry or tunnel advances. In Fig. 2 the boiler G is placed above the bituminous sands B and the steam pipe E, with suitable connections, is carried through the overburden A into the sands B. The pipe (or pipes) H is sunk through the overburden A as before for the removal of liquids I.

A high percentage of bitumen is found in these deposits of bituminous sands as well as other substances. These sands differ from petroleum shales in that the latter are clay rock formations containing petroleum or bitumen, whereas these sands are not in a rock formation but in a loose sands, which will not, however, fracture when treated with explosives or flow into wells drilled for the purpose. Owing to the fact that pure sand forms the greater part of these bituminous sands, my process treats the deposit in mass without removal, because of the great cost of removing these sands and treating them by various processes to cause separation of the various parts.

The pipe E carrying super heated steam from boiler G is introduced into the sands F as heretofore mentioned. This steam softens and dissolves the mass, permitting the bitumen and other substances to separate from the sand. The liquids I rise to the top of the part under treatment, while the sands sink under the effect of gravity.

After sufficient separation and settlement of the bitumen and other substances from the sand has taken place the liquids may be drawn off from pipe or pipes H into storage tanks, etc. These liquids may be removed as the depth of the hole increases, or, preferably, the hole will be sunk to the bottom of the deposit or to the limit of the property. From here the steam will commence its action, and then the steam pipe or pipes may be withdrawn slightly so that a higher portion may be treated. Thus the bitumen and other substances are separated from the sand and the whole mass is treated.

The action of the steam on the sands may be accelerated when the sands do not respond readily to the action of the steam, by the addition of suitable chemicals such as may be found desirable or of assistance in causing the bitumen and other substances in the sand to form a liquid. I also purpose where conditions are favorable to an increased pressure, to apply such pressure or combination of pressure and vacuum in order that the liquids in one part may flow to another part, thus the whole being more readily connected for removal from the sands to tanks or containers on the surface.

It is ~~well known that~~ various processes have been used for the extraction of bitumen and other substances from these sands, but have not been attended with success owing largely to the cost of removing the overburden and extracting the sands, finding suitable apparatus for the treatment of large masses and the non-response of the sands to treatments of heat alone.

I CLAIM -

1. The process of treating natural deposits of bituminous sands consisting of penetrating the natural overburden and sands to the bottom of the deposit or limit of the sands being treated, introducing steam into the sands adjacent to the bottom or limit of the deposit thereby liquifying the bitumen and permitting the sands to settle under gravity, progressively treating the remaining portions of the sands with steam and allowing all the sands to be separated from the liquid bitumen under gravity and finally removing the liquified bitumen without the necessity of removing the sands.

2. The process of treating natural deposits of bituminous sands claimed in claim 1 characterized by introducing chemicals into the deposit of sands to facilitate liquifying of the bitumen.

3. The process claimed in claim 1 in which increased steam pressure and a vacuum are utilized to facilitate flow of the liquid bitumen from one part to another part of the deposit and permit of finally removing the liquid bitumen from the settled sands.

~~Calgary, Alberta.~~
~~November 9th, 1922.~~
~~Signed in the presence of~~

[illegible]ocess for the Separation and
[illegible]traction of Bitumen and Other 245317
[illegible]stances from Natural Deposits
[illegible]tuminous Sands.

12 +

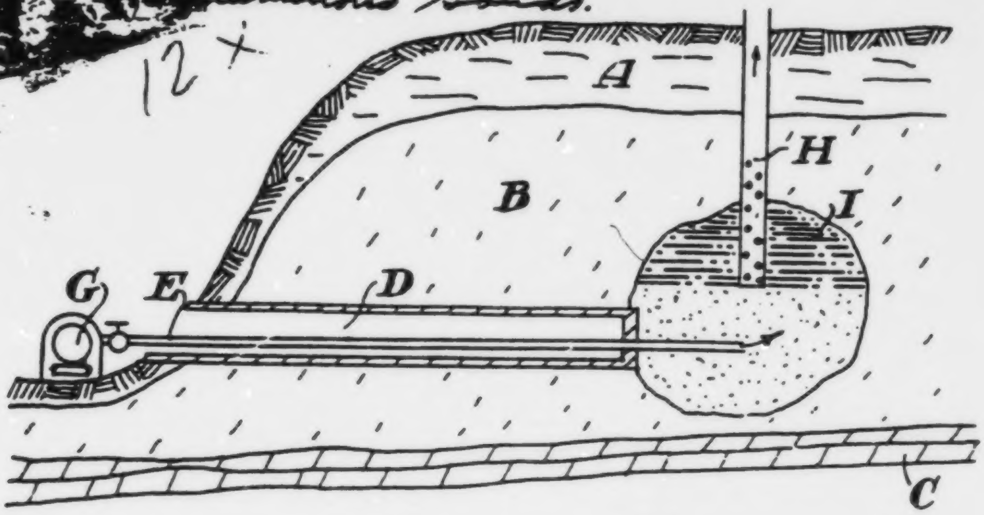

Fig. 1

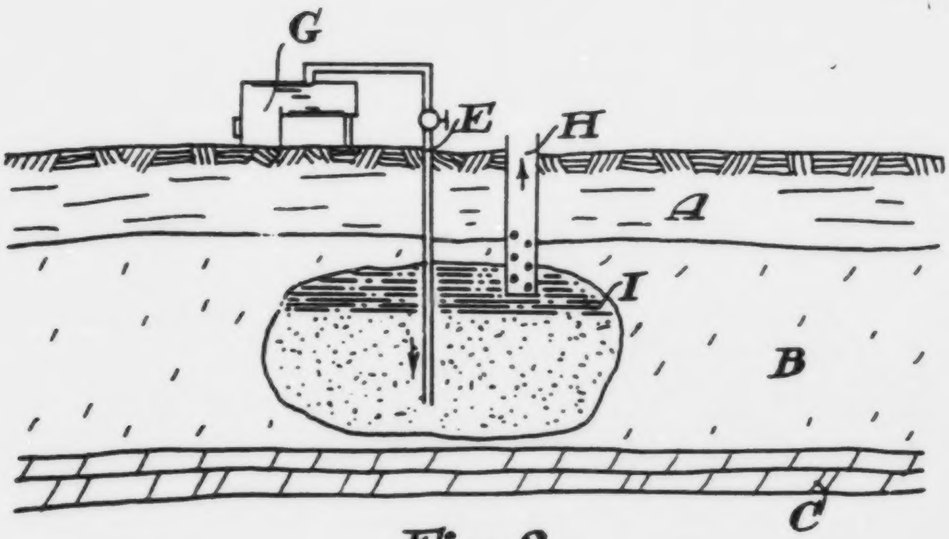

Fig. 2

Certified to be the drawings referred to in the specification hereunto annexed.

Calgary, September 14th 1923

W Ferguson
Inventor.

Witnesses

010128

Alberta OIL

INFORMATION CENTRE

Oct. 31, 1967 D. R. HOLBERT ETAL 3,349,845

METHOD OF ESTABLISHING COMMUNICATION BETWEEN WELLS

Filed Oct. 22, 1965 3 Sheets-Sheet 1

Fig. 1.

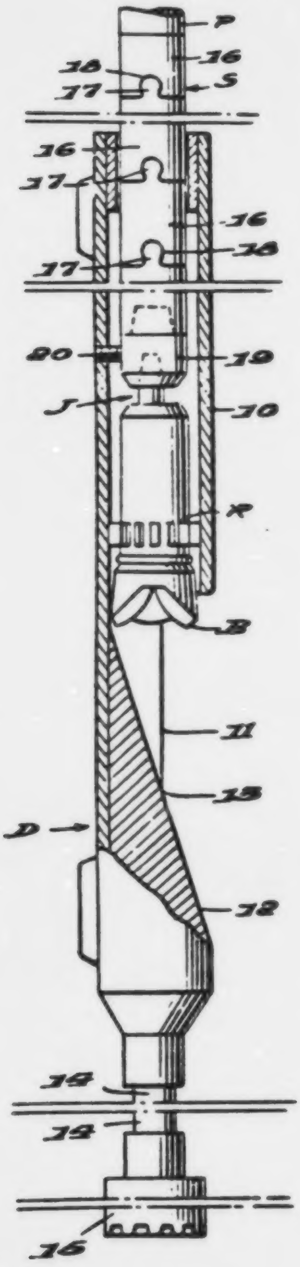
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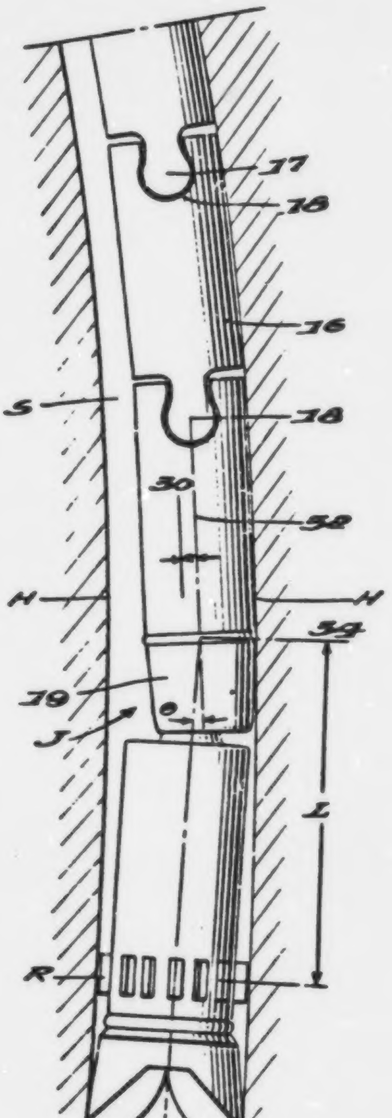
Fig. 2.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B

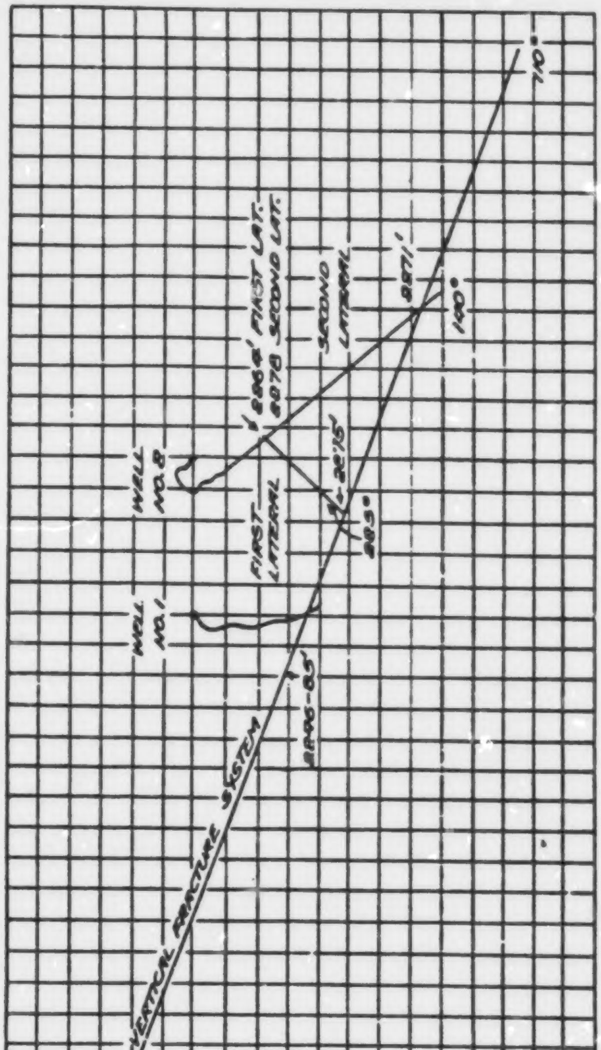
INVENTORS

DON R. HOLBERT,
BRUCE F. GRANT,

Oct. 31, 1967 D. R. HOLBERT ET AL 3,349,845

METHOD OF ESTABLISHING COMMUNICATION BETWEEN WELLS

Filed Oct. 22, 1965 3 Sheets-Sheet 2



110°
8968' FIRST LAT.
8978 SECOND LAT.
SECOND LATERAL
8971'
140°
WELL NO. 8
FIRST—LATERAL
26°15'
283°
WELL NO. 1
8895-85'
VERTICAL FRACTURE SYSTEM

Fig. 3.

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METHOD OF ESTABLISHING COMMUNICATION BETWEEN WELLS

Filed Oct. 22, 1965 3 Sheets-Sheet 3

Fig. 5.

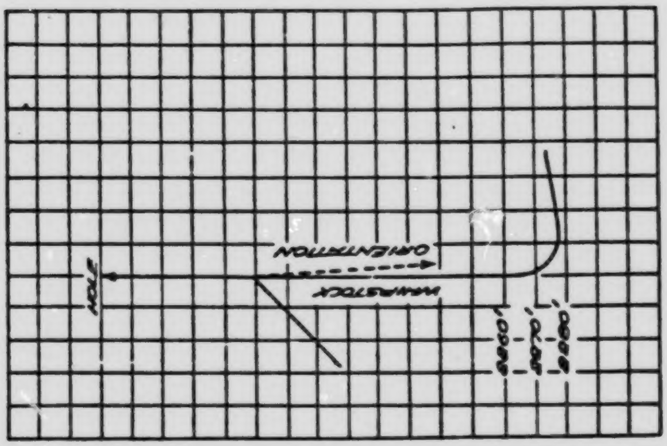
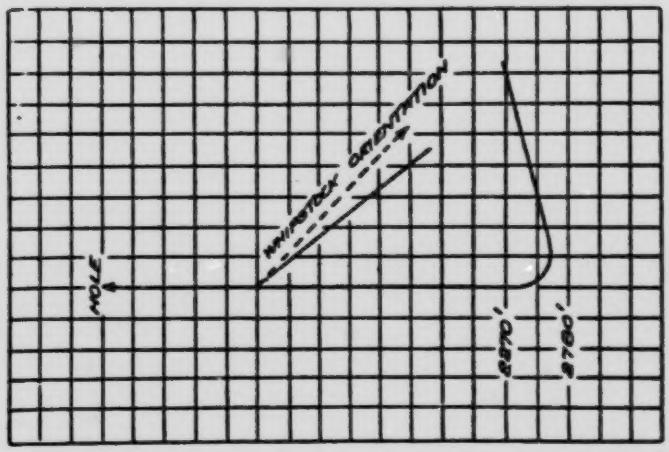

HOLE
ORIENTATION
WHIPSTOCK
8850'
8870'
8880'

Fig. 7.


HOLE
WHIPSTOCK ORIENTATION
8870'
8780'

INVENTORS
DON R. HOLBERT,
BRUCE F. GRANT,

United States Patent Office

3,349,845
Patented Oct. 31, 1967

3,349,845
METHOD OF ESTABLISHING COMMUNICATION BETWEEN WELLS

Don R. Holbert, Huntington Beach, Calif., and Bruce F. Grant, Tulsa, Okla., assignors to Sinclair Oil & Gas Company

Filed Oct. 22, 1965, Ser. No. 501,394
5 Claims. (Cl. 166—4)

This invention relates to a method for recovering hydrocarbons from an underground petroliferous formation. Such hydrocarbons are solids or viscous liquids, generally unflowable at ordinary formation temperatures, and are often characterized by having an API gravity less than about 25°. Such a viscosity characterization applies to "solid" hydrocarbons as well. The method is, furthermore, concerned with formations which are essentially impermeable to flow of their native fluid and, generally, the applicable formations have essentially no gas permeability or an effective gas permeability of less than about 10 millidarcies.

The recovery of viscous crude hydrocarbon material from formations of this type is important in those areas where such hydrocarbons are, or may soon be, the principal indigenous source of petroleum liquid hydrocarbons or where the cost of finding and producing crude petroleum has risen so that the viscous oils and other non-flowable hydrocarbons can be recovered and refined on an economically competitive basis. The formations which contain the non-flowable hydrocarbons may be one of a number of types including tar sands, oil shale, etc. Oil shale, for example, is a fine-grained, compact sedimentary rock having splintery uneven laminae having essentially no gas permeability which may contain about 10 to 65, or more, gallons of oil per ton in the form of a solidified, resinous organic material which clings to the siliceous shale particles. Hereinafter the invention will be described with reference to oil shales although it is not so limited.

Although quarrying and surface retorting of shale is practiced in some places to recover hydrocarbons, removal of the overburden or mining in many areas is generally impractical. Also, the use of secondary recovery methods such as heat in situ to fluidify, that is, to melt, distill or decompose the non-flowable hydrocarbons is not always a panacea. In such secondary recovery methods, the entire formation may be heated at least to the fluidifying temperature of the hydrocarbons which then drain out to the production well or wells. However, such a conduction process is expensive since the whole formation must be kept heated, usually by burning saleable fuel, and a good deal of heat is wasted to the overburden and the substrata. Further, these heating methods generally require the output well to be rather close to the input well and a distance of less than about fifty feet between input and output wells is undesirable from an economic standpoint. Another type of secondary recovery process involves forcing a hot gas through the formation to heat the formation largely by convection and to both fluidify and clean out the hydrocarbons. However, the formations frequently have essentially no "natural" gas permeability or a permeability less than about 10 millidarcies or even less than about 5 md., for example, less than about 1 md. In many of these formations, therefore, secondary recovery methods which involve gas circulation are not feasible.

The process of this invention avoids the above-mentioned difficulties by providing a corridor of reduced resistance to gas flow in the formation between an input well and an output well which corridor can be converted into a hot passageway and can be maintained while hydrocarbons are recovered by thermal means. The corridor of reduced resistance in this invention is produced by first fracturing the petroliferous formation at one of the wells

to produce a vertical fracture system generated outwardly from this well and thereafter drilling at least one communicating, essentially horizontally extending bore from the other well which intersects the fracture system to establish communication between the two wells. In other words the corridor is a part of the formation stretching continuously from the input well to the output well through which gases from the input well can pass to the output well in preference to passing through the formation in general. Once the corridor is established, the hydrocarbons are recovered by igniting and maintaining a fire in the bottom of the input well to heat the bore hole and corridor and liquefy and/or vaporize hydrocarbons which are gradually removed from the formation to the output well and recovered.

The first step, i.e., fracturing, when applied to a relatively imperable formation, results in the opening of at least one substantially continuous fracture or corridor extending outwardly from the first well. This corridor, which is later converted to the hot passageway, serves as the core or axis for the hot passageway. It has been recognized in this invention that fracturing in formations such as oil shale results in a vertical fracture system rather than the more conventional horizontal fracture systems. These vertical fractures will be from one or two, e.g., several, feet up to 40, or even 50, feet in height and will, in general, run for long distances outward from the well at which fracturing is accomplished. The width of the fractures is small, e.g., from about ¹⁄₁₆ to ⅜ inch, and varies along the length of the fracture. If desired, the fractures can be propped open with sand or other granular solids which do not prevent fluid flow to the output well. It is to be understood that the corridor is sufficient to provide only a small fraction of the fluid-carrying capacity of the entire stratum.

Fracturing is accomplished by pumping quantities of gases, heated if desired, or liquids into the input well, and/or output wells, and increasing the pressure until seams or fissures of the desired fluid flow capacity have been opened in the stratum. The location of the fracture can be controlled by notching the bore prior to pumping of the fluid and straddling this notch with packers to leave an area of open formation.

Following fracturing of the formation, e.g., at the input well, the orientation of the fracture system is determined using conventional techniques, for example, by impression packers, and a second well is drilled. The location at which this second well is drilled is determined by the orientation of the vertical fracture system and is, preferably, within about 100 feet of the projected location of the vertical fracture. The distance between the two wells is determined by economic considerations, but, in general, will not be in excess of about 1000 feet, preferably 500 feet. A horizontal bore is then drilled from this second well to intersect the vertical fracture system and establish communication between the two wells.

In general, horizontal drilling is accomplished using the apparatus described in copending Holbert application Serial No. 493,970, filed concurrently herewith. A deflecting tool is positioned in the main bore of the well adjacent the desired formation at which the horizontal bore is desired, i.e., at which the bore will intersect the vertical fracture. The drilling apparatus used in combination with the deflecting tool to actually effect horizontal drilling of the horizontal bore comprises several structures all of which are attached to the lower end of the usual drill pipe and includes a flexible shaft, a universal or knuckle, joint, a reamer and a drill bit which are connected together. The flexible shaft may be or any suitable construction which will permit the shaft to follow a drill bit into a horizontal hole which is being drilled off outwardly from the main bore, and yet, be capable of transmitting torque to the drill bit.

It has been found that in order to be able to drill a horizontal bore in a desired direction and maintain this direction, as desired in the instant invention that the bit-reamer-knuckle joint configuration must meet specific design requirements. The hole drilled in producing the horizontal bore, i.e., in going from vertical to horizontal, is slightly elliptical in cross-section and is actually curved. The angle building capacity of the tool described the radius of curvature of this hole, i.e., 5° per foot of angle build gives a radius of curvature of about 11.5 feet or, in other words, with a 5° per foot of angle build the bore will go from vertical to horizontal through a curve having a radius of curvature of 11.5 feet. For a given radius of curvature RC, to provide accurate horizontal drilling in a desired direction without substantial deviation from this direction, the knuckle joint to reamer spacing L and drilled hole centerline to knuckle joint centerline spacing *a* must be in accordance with the equation: $R=L^2/2a$. L is measured from the centerline of the knuckle joint to the centerline of the reamer, both in the plane of contact to the drilled bore hole, and *a* is the distance between the centerline of the reamed hole to the centerline of the knuckle joint. Also, the reamer must cut in order for the designed angle building capability to be developed.

In general, the size of the reamer used will vary from a size sufficient to cut or ream the bore and prevent stabilization of the bit to the size at which the reamer requires so much force to cut that the axial applied load on the drilling apparatus is insufficient to drill the bore. A ⅛ inch cut by the reamer is preferred. If the reamer does not cut, the reamer becomes a stabilizer, lifting the knuckle joint toward the centerline of the hole, reducing dimension *a* in the above equation and increasing dimension L. Furthermore, since the axial applied load used in drilling the bore provides the moment causing the reamer to dig down and the bit to dig up, if the axial load is diminished from friction or less applied drill collar weight, the force against the reamer may fall below a threshold value causing it to stabilize and not cut. Accordingly, the applied drilling weight has a critical lower limit. For the bit-reamer-knuckle joint configuration, the force against the reamer is about 50 percent of the axial load.

A blade reamer is preferred in the present invention although a spiral or other type can be used. The type of bit used is determined by the rock being drilled in accordance with standard considerations. The applied drilling weight required in accordance with this invention is a function of the rock being drilled, i.e., is that amount sufficient to make the reamer cut in the particular rock being drilled. In general, the applied weight is in excess of about 7,000 lbs. for oil shale.

The direction and radius of curvature RC will be chosen as desired in order to drill toward the fracture produced at the output well and the chosen radius of curvature put into the formula described above to define the size of the equipment to be used. In general, a small radius of curvature is preferred because the directional characteristics are better achieved with a small radius of curvature. The radius of curvature is generally spoken of in terms of the desired angle of build which is generally from about 2° per foot to about 6° per foot with approximately 5° per foot being a preferred angle of build. The upper limit for the angle of build is determined by the flexibility and strength of the flexible shaft being used. Too high an angle of build will generate torque in such an amount as to tear up, i.e., shear, the pipe. With a 5° per foot angle of build the radius of curvature is approximately 11.5 feet and with a 2° angle of build the radius of curvature is approximately 28 feet. A further important consideration in the present invention is the drilling fluid used in the drilling operation. The drilling fluid is preferably close in consistency and composition to water and contains an extreme pressure agent in an amount sufficient to coat the pipe.

With the horizontal drilling apparatus of the present invention, it is possible to drill accurately in a desired direction horizontal bores from a main bore to distances in excess of about 100 feet horizontally outward from the main bore with the limit being that defined by the amount of torque required to be applied to the pipe. If the torque exceeds the load limit of the pipe, the pipe will shear.

The deflecting tool used in combination with the drilling apparatus of this invention is commonly called a whipstock and ideally should have the same radius of curvature RC along its length as defined above which is the radius of curvature of the curve through which it is desired for the flexible pipe to pass in going from a vertical to a horizontal bore. The whipstock in general should have a radius of curvature or an angle with respect to the vertical of at least 5°, and up to about 20°, preferably at least 10 to 12° up to about 15 to 18° depending upon the length of the whipstock. It is preferably, if the radius of curvature is not the same as RC described above, to have the whipstock angle slightly higher than the desired angle of build which determines the radius of curvature RC.

Other objects of this invention will become apparent from the following description taken in connection with the accompanying drawings in which:

FIGURE 1 is a longitudinal cross-sectional view of drilling apparatus embodying this invention, the horizontal drilling apparatus being shown associated with a deflecting tool and conditioned for placing in a main well bore prior to the beginning of drilling operations to make a horizontal bore;

FIGURE 2 illustrates the bit-reamer-knuckle joint configuration of this invention;

FIGURE 3 illustrates in plan view a plot of an example of this invention wherein a vertical fracture system from one well is intersected by horizontal bores from a second well; and

FIGURES 4 and 5 are side elevation plots of the horizontal bores illustrated in FIGURE 3.

Referring to the drawings in detail and first to FIGURE 1, there is shown a drilling structure for drilling horizontal bores from a main well bore. These horizontal bores are drilled after the main bore is drilled into the oil-bearing strata and can be drilled from the main bore at or near any depth of the main bore and the direction thereof can be at any point of the compass. In some cases the angle of the horizontal bore with respect to the axis of the main bore will be in excess of 90°. The horizontal bores reach points a considerable distance, e.g., on the order of 100 feet or more, in a generally horizontal direction from the main bore.

As shown in FIGURE 1, there is provided a deflecting tool, generally designated as D, which has a tubular upper end 10 and a window 11 at its lower end. Mounted in the lower end of the tubular member opposite the window is a plug portion 12 provided with a surface 13 angularly positioned with respect to the longitudinal axis of the deflecting tool, which surface is ordinarily called the deflecting surface. Surface 13 is opposite the window 11 so that the drilling bit can be deflected toward a direction which is at an angle to the axis of the tubular part of the deflecting tool. A tail pipe 14 is secured at the lower end of the deflecting tool. Tail pipe 14 has an anchor 15 at its lower end, the purpose of which is to anchor the deflecting tool D in the main bore and at the desired distance above the bottom of the main bore. The length of the tail pipe 14 will be selected so that when the anchor member 15 is on the bottom of the main bore, the deflecting surface 13 will be at the point in the main bore where it is desired to begin drilling of the lateral bore.

The horizontal drilling apparatus which embodies this invention comprises in combination with the deflecting tool D several structures which are attached to the lower end of the usual drill pipe P including a flexible shaft or pipe

S, a knuckle or universal joint J, a reamer R and a drill bit B, connected together as shown. The flexible shaft S may be of any suitable construction which will permit the shaft to follow a drill bit into a horizontal hole which is being drilled laterally from the main bore and yet be capable of transmitting torque to the drill bit. The particular shaft shown comprises a number of tubular sections 16 joined together by means of interengaging lobes 17 and sockets 18.

The universal or knuckle joint J is mounted in the drilling structure at the lower end of the flexible shaft S and forms a connecting joint between this shafting and the drill bit B together with the reamer R which is attached at the rear of the drill bit. The joint J provides a universal connection and is so constructed that drilling torque can be transferred from the flexible shafting to the drilling bit to accomplish drilling operations. Such universal joints are well known in the art and further description is believed unnecessary. To attach the upper end of the joint structure J to the lower end of the flexible shafting S there is provided a tapered sub 19, see FIGURE 2. The drill bit B, already referred to, may be of any suitable construction such as the rock type having rotary cutting members as shown. The reamer R which is located directly behind the drilling bit B follows the drilling bit as it cuts the lateral or horizontal bore and reams out the cut bore.

Before inserting the horizontal drilling apparatus just described into the well bore to perform the drilling of the lateral bore, the deflecting tool will be connected to the drilling bit and flexible shafting so that the relationship thereof will be known. This is accomplished by means of a frangible pin 20 arranged between the tubular part 10 of the deflecting tool and the sub 19 above the joint J. The position of the pin will be such as to hold the bit B slightly above the deflecting surface of the deflecting tool, as shown in FIGURE 1. With this connection, the whole drilling structure shown in FIGURE 1 will then be lowered into the main bore. It will be noted that the structure will be arranged so that the anchor 15 will rest on and press into the bottom of the main bore. The distance that the deflecting tool is above this bottom will depend upon the length of the tail pipe 14. Before placing the anchor 15 on the bottom of the main bore, the deflecting surface 13 of the deflecting tool D will be oriented, that is, placed in the desired compass direction and at the desired depth to drill off from the main bore to produce the horizontal bore. The orienting of the deflecting surface on the deflecting tool is accomplished by conventional methods well known to one skilled in the art and when such is done the anchor will then be placed on the bottom of the main bore where the teeth thereof will dig into the bottom surface and prevent rotation of the deflecting tool relative to the bore.

Drilling operations can now be commenced and these are begun by first applying a downward pressure on the drill pipe P, which will result in severing the frangible pin 20 and disconnection of the drilling structure from the deflection tool. As the drill pipe P is rotated, the drill bit B will also be rotated, and upon continued lowering of the drill pipe, the drill bit will be deflected by the deflecting surface 13 through the window 11 of the deflecting tool and the drilling bit will then begin to cut a hole off from the side of the main bore and in a direction as determined by the angle of the deflecting surface. Due to the fact that the diameter of the members of the joint J is less than the drill bit B, the joint, when acted upon by downward forces present during drilling, will be pushed over toward the deflecting surface 13 of the deflecting tool D. Consequently, this tendency of the joint to move toward the deflecting surface will result in the placing of the axis of the drilling bit B and also the coinciding axis of the reamer R to be at a slight angle to the deflecting surface. Thus, as soon as drilling bit B reaches a point where it is passing off from the deflecting surface, the bit will tend to dig toward the top side of the bore being drilled and, as a result, the bore will be drilled in a curve, i.e., at an angle to the vertical, and not in a straight or substantially straight line. This is referred to as "building" angle. If there were no tendency for the drilling bit to build angle as a result of the structure employed, the bore would be drilled in a straight direction substantially the same as that of the deflecting surface as extended, and the axis of the lateral bore would always maintain an angular relation with the main bore which would be substantially the same as the deflection surface. However, with the improved drilling construction of this invention embodying the universal joint J having a particular relationship with the reamer R, both as to diameter and spacing, the axis of the drilling bit will be at a slight angle to a line tangent to the lateral bore at a point where the drilling bit is cutting, and this angle will be such as to direct the drilling bit toward the high side of the lateral bore as drilling continues. As the drilling bit is rotated and the angle continues to "build," the bore cut will have a curvature which will have a substantially uniform radius of curvature. If the lateral bore is continued to be drilled outwardly, it will reach a horizontal direction with respect to the main bore which is assumed to be vertical. During all the drilling, fluid is circulated through the flexible shafting S, joint J and reamer R to the drill bit B. If necessary, the flexible shafting can be lined with a suitable rubber tubing to prevent leakage at the joints.

After the desired length of lateral hole is drilled and the fracture has been intersected, the flexible shafting and other drilling structure can be pulled back into the deflecting tool and then the whole structure removed from the bottom of the main bore, or if it is desired to drill additional drain holes off from the main bore, the deflecting tool can be raised off the bottom of the main bore and after turning the drill pipe to a new oriented position it can be again lowered and a lateral bore drilled off in another direction, which will be determined by the direction of the deflecting surface of the deflecting tool.

FIGURE 2 illustrates the required relationship between the reamer R and the joint J. This specific relationship is one of the distance L between the pivotal axis of the joint J, represented by line 34, and the centerline 36 of the reamer R and of the difference a between the radius of the joint and the radius of the reamed hole H, i.e., the distance between the centerline 30 of the reamed hole H and the centerline 32 of the shaft S. This specific relationship of dimension is critical to accomplish the desired drilling of the horizontal bore through building of angle and to accomplish control, i.e., maintenance in the direction of horizontal drilling. The radius of curvature RC of the bore drilled is given by the equation $L^2/2a$ and will be uniform once drilling is begun. If the curvature of the bore is allowed to get off course, i.e., if the bore is drilled in the wrong direction, the curvature is irreversible. In general, an angle of build, i.e., a radius of curvature, is chosen for the drilling apparatus and from this the desired dimensions are chosen. Since the knuckle joint must be smaller than the drill bit and in general has a diameter equal to the flexible shaft S, the dimension a is also relatively set such that in constructing the apparatus in accordance with this invention the dimension L is of primary importance. The reamer R must not only ream out the bore H, but must cut to develop the designed and required angle building capability of the drilling apparatus. This cut is preferably approximately ¼ inch, although in general the amount may be only that sufficient to prevent the reamer from acting as a stabilizer and straightening out the flexible shafting S. The upper limit of cut is determined by the amount of cutting which would apply too great torque load to the shafting S and tear the shafting apart.

The following example serves to illustrate the formation of a corridor between two wells in accordance with this invention.

A first well was drilled. A plot of hole deviation is shown in FIGURE 3 on a plan view. A notch was cut in this well at 2,262 ft. depth using a four jet tool with the hold-down device set at 2,202 ft. The fluid used was 3,000 gal. of water containing one lb. per gal. of sand concentration. The fluid was pumped for 20 minutes at a 4 b.p.m. rate while rotating the drill pipe at 6 r.p.m. Lynes straddle packers were set at 2,230 ft. and 2,271.4 ft., top and bottom centers, respectively, and a breakdown with 25 barrels of water was made. A sand-gelled water fracture treatment was then made through 2⅞" drill pipe with a packer set at 2,230 ft. using 30,000 lbs. of 20/40 mesh sand in 15,000 gal. of gelled water.

Packer and pumping tests indicated vertical communication between the 2,246 and the 2,293 ft. zone. A non-oriented impression packer was run to 2,265.4 ft. and an impression of a vertical fracture was obtained. Five impression packers were run to map the fracture, see FIGURE 3.

A second well was drilled. The second well was located in the direction of the fracture planes with a surface location approximately fifty feet from the first well. The second well was plugged for a whip-stock setting at a depth (2,264 ft.) selected for drilling into the vertical fracture system and a whipstock was set in the direction of the fracture system.

The first three feet of a first lateral were drilled with the bit and stabilizer at the lowest possible weight. The bit and stabilizer assembly were then pulled and the bit, reamer and 5° per foot knuckle joint assembly run. With 8,000 lbs. drilling weight, the direction still shifted 48° in only eight survey feet. The drilling weight was further decreased to 7,000 lbs. for drilling the next 9 ft. and the survey showed no change in direction. A stabilizer was run after drilling almost 22 ft. and the hole was drifted to a total depth of 42¾ ft. (34¾ ft. of horizontal distance). At this depth pressured air from the first well blew out in the second well indicating that the drill had cut through the fracture. The data for this lateral are shown in Table I and the lateral is plotted in FIGURES 3 and 4.

TABLE I.—FIRST LATERAL-WHIPSTOCK ORIENTATION S3°E

Drilling Depth, ft.	Drilling Weight, lbs.	Penetration Rate, ft./min.	Survey Depth, ft.	Deviation, deg.	Direction, deg.	Vertical Angle Build, deg./ft.	Horizontal Angle Build, deg./ft.
2,263.9	------------	Start	------------	------------	------------	------------	------------
2,266.9	1,000-2,000	------------	------------	------------	------------	------------	------------
2,272.9	8,000	.14	2,271.9	36	S45W	4.5	6
2,282.7	7,000	.14	2,280.7	76	S45W	4.4	------------
2,285.7	7,000	.08	2,283.7	89	S48W	4.7	1
2,293.7	7,000-8,000	.14	2,291.7	96	S49W	------------	.1
2,306.7	8,000	.16	2,304.7	98½	S49W	.3	------------

A second lateral was initiated at a 2,273 ft. depth. The first survey of the second lateral indicated the direction to be about 12° clockwise from the whipstock setting. The angle build and drilling characteristics were excellent. Slight tooth breakage was observed. A stabilizer was run after drilling 18 ft. The lateral was stopped at a depth of 78 ft. This measures 72 ft. of horizontal distance. A communication test with a packer set between the two laterals resulted in a strong, turbulent flow of mud through the tubing when the first well was air pressured. The data for the second lateral No. 5 are shown in Table II and FIGURES 3 and 5.

TABLE II.—SECOND LATERAL-WHIPSTOCK ORIENTATION S47°E

Drilling Depth, ft.	Drilling Weight, lbs.	Penetration Rate, ft./min.	Survey Depth, ft.	Deviation, deg.	Direction, deg.	Vertical Angle Build, deg./ft.
2,272.8	------------	Start	------------	------------	------------	------------
2,275.8	1,000-3,000	.04	------------	------------	------------	------------
2,293.8	7,000	.15	2,288.8	87	S35E	5.4
2,303.8	7,000	.19	------------	No survey	------------	------------
2,310.8	7,000	.19	2,306.8	95½	S39E	------------
2,317.8	7,000	.12	------------	No survey	------------	------------
2,318.8	7,000	.11	------------	No survey	------------	------------
2,330.8	7,000	.16	------------	No survey	------------	------------
2,350.6	7,000-6,000	.11	2,348.8	108½	S40E	.3

The mud system used in drilling the laterals was a salt water emulsion containing 90 pds./bbl. salt, 2.8 pds./bbl. diesel oil, 2.8 pds./bbl. D.M.E. and 9.5 pds./bbl. EP mudlube. The characteristics of the mud system were:

Characteristics:

Weight	pds./gal.	9.6–9.7
Viscosity	sec.	31–33
Chloride ion	p.p.m.[1]	247,–255,000
Oil	percent	3
Water	do	87–89
Solids	do	8–10
Lubrication properties		Yes
EP Lub. properties		Yes

[1] Diluted down to 100,000 p.p.m.

The output of the compressor used for testing was 66 M c.f.d. during the test for communication of the first lateral. After allowing the second well to blow overnight, an air flow of 64 M c.f.d. was measured with the orifice well tester, indicating 97% communication. The injection pressure was dropping at 1,150 p.s.i. from 1,550 p.s.i. when the test was ended.

The same basic procedure was used to test the second lateral. A ballon packer was run to 2,268 ft. The blowout preventers were closed and air injection was started into the first well. The pressure stabilized at 1,250 p.s.i. with an injection rate of 64 M c.f.d. After seven hours the second well was still making a strong flow of water and mud up the drill pipe. The test was discontinued since this, plus the water flow while drilling, was considered ample evidence of good communication.

Hydrocarbons are recovered from an oil shale formation in accordance with this invention by developing a corridor between a first and a second well, now referred to as the input and output wells, as described above. In a preferred embodiment of this invention a fire is maintained in the bore hole of the input well by burning a fuel gas therein after the corridor is formed, i.e., communication is established, between the input and output wells. The ignition and maintenance of the fire may be performed by conventional burner means and the temperature of the fire is allowed to increase to at least about 700° F. The bore hole temperature can be maintained at this minimum level by regulating the proportions of fuel gas and combustion supporting gas sent through the bore hole. The heat in the bore hole may exceed 700° F., i.e., up to a temperature where the casing or bore hole wall of the input well will be damaged, but the temperature of the formation adjacent the input bore hole will usually not be greater than about 1,500° F., frequently not greater than about 1,000° F. Since the work required in pumping a gas is proportional to the difference in the squares of the initial and final absolute pressures, less work is generally required to bring about a given pressure difference when a higher initial pressure brings this difference closer to 0. For this reason, the pressure in the output well is preferably maintained above atmospheric pressure and usually at a minimum of about 200 p.s.i.g., with the maximum being somewhat below that pressure which would lift the overburden. The pressure in the input well during the creation of the hot passageway need only exceed the pressure in the output well by just sufficient pressure to bring the fuel and combustion supporting gases from the input well through the corridor. This difference in pressure of input well gases over output well gases is insufficient to cause significant gas flow through portions of the stratum other than the corridor. In travelling through the passageway the gases may pick up additional fuel components from the adjacent formation and so may be recycled back to the input well to exploit this fuel value and the heat of the exhaust gas. Alternatively the exhaust gases may be passed in a direct or indirect heat exchange relationship with the input gases to conserve heat.

The fire in the bottom hole of the input well heats the walls of the input well and the walls of the corridor become heated by the moving gases. Heat is transmitted primarily by conduction from these heated walls into the formation, and gradually a zone in the formation adjacent the walls of the corridor will become heated. The gases moving through the corridor are, of course, cooled by contacting the walls of the formation, so that it takes some time for the heated zone or hot passageway to reach a temperature of at least 700° F. all the way from the input well to the output well. The conduction of heat into the stratum which takes place from the walls of the bottom hole of the input well and the walls of the corridor heats up a passageway having a smaller transverse cross-section as it approaches the bottom hole of the output well.

Heating under mild gas pressure is continued until a heated zone, i.e., a mass of formation having a temperature of at least about 700° F. is created which extends for at least about 40 or 50 feet along the vertical wall of the bottom hole of the input well and this 700° F. isotherm can even extend the complete height of the hydrocarbon-containing stratum. The heating can also raise the temperature of the entire stratum between the input and output wells, and it can be continued until essentially all of the stratum between the input and output wells is heated to the required minimum temperature, but this is usually neither necessary nor desirable. The approximate 700° F. minimum temperature is sufficient to fluidify, that is, to liquefy and/or vaporize hydrocarbons in or recoverable from the formation. As the heat of the walls of the bore hole and the walls of the corridor including the fracture and horizontal bore is transmitted to the surrounding formation, the kerogen or other petroliferous material contained in the heated zone is affected and the heat thus serves gradually to remove a certain amount of hydrocarbons from the zone, which are conducted by the corridor to the output well for recovery. Since the creation of the hot passageway is carried out under the minimum gas pressure and since the corridor provides much lower resistance to the passage of gas than the body of the formation, there is little penetration of heated hydrocarbons into cold portions of the formation during heating. As hydrocarbons are removed from adjacent the corridor to the output or production well, the permeability of the heated zone is increased creating a larger passageway for

gases. When a later gas sweep or burning wave treatment, conducted under substantially increased gas pressures, is applied to this formation, the hydrocarbon materials which are taken from the formation can travel to the output well without being exposed to congelation temperatures and, therefore, without clogging all passageways and requiring uneconomically high pressures for the creation and maintenance of gas circulation.

The shape of the heated zone is determined by the characteristics of the formation, for example, the specific heat of the formation material and the convective ability of the corridor. The same factors, as well as the ignition temperature of the fuel, will also determine how high a temperature above about 700° F. may be reached in the heated zone. The time required to heat the formation to create a base for the passageway at the wall of the input well bottom hole having the desired 700° F. temperature and least about 40 or 50 feet in diameter also depends upon how much heat is consumed in fluidifying the hydrocarbons of the formation. The rate of gas injection and the composition of the injected gases govern to a large extent the amount of time taken for the complete length of the fracture to reach the desired temperature.

The heated passageway is maintained at a temperature of at least about 700° F. during a subsequent hydrocarbon recovery procedure which employs passage of gas from the input well, through the preheated formation or passageway, and to the output well at a pressure higher than employed in creation of the heated passageway. In order to insure flow of the gas through the formation itself, rather than through the generally more permeable, original corridor, the end of this corridor adjacent the input well may be plugged, to a greater or less extent, depending on the relative permeability of the corridor and the adjacent heated zone of the formation.

A simple way to recover hydrocarbons from the formation is the injection of a gas into the formation from the input well to fluidify hydrocarbons in the formation. This sweep gas, preferably at a temperature of at least about 700° F. and, of course at a pressure sufficient to penetrate the formation itself, travels through the hot passageway and maintains the passageway at this temperature. The passage of the gas may also serve gradually to heat zones in the formation surrounding the hot passageway to the approximate 700° F. mark causing fluidification of the hydrocarbons contained therein. Liquid hydrocarbons drain from newly heated zones into the hot passageway and travel to the output well; vaporized hydrocarbons are entrained in the sweep gas and may be separated therefrom at the production well exit. Gradual removal from the formation of the hydrocarbons, combined with heating of the formation, serves to enlarge the cross-sectional area of the hot passageway as zones, remote from the corridor and from the input well, increase in their temperature and gas permeability. The composition of the sweep gas is not too important, but preferably it is a non-combustion-supporting gas such as flue gas or steam.

Alternatively, after the hot passageway and heated formation are established and the corridor plugged, if necessary, a moving burning wave can be generated in the previously heated formation, for instance, according to the process of the aforementioned U.S. Patent No. 2,780,449. As an example, the proportions of fuel gas and combustion supporting gas sent to the fire in the bottom hole of the input well are adjusted, if necessary, to give a temperature level in a portion of the formation of at least about 700° or 1000° F. or higher depending on the combustion temperature of the carbonaceous residue in the siliceous material in the vicinity of the input well bore hole. The pressure is increased to a value sufficient for the combustion gases to penetrate at least the portions of the formation which have been heated by conduction. The gas flow rate should be as high as is practical at a pressure sufficient to maintain passage through heated portions of the formation from the input well to the output wells or output zone. When the heated zone, that is, a zone having a temperature of at least about 700° F., has been established at the wall of the input well, burning in the input well is discontinued and the heated zone is moved as a thermal front or wave radially outward into the formation through the area preheated by conduction and in the direction of the output well. This can be performed by substituting an unheated substantially noncombustible oxygen-containing gas stream for the fuel-gas-air mixture at the input well so that the region of peak temperature is moved gradually outward into the formation from the input well. In this manner the injected gas stream is an effective heat transfer medium absorbing heat as it approaches the peak temperature region of, for example 700 to 1000 or 2000° F., and transferring heat absorbed in the process to the regions of the formation beyond the hot zone. Gases, both those injected and those produced by heating, and fluidified hydrocarbons flow through the heated passageway to the output well. The pressure on the input gases may force some of the heated gases into unheated zones within the formation to secure recovery of hydrocarbons from these zones or these zones may be heated by conduction in advance of the burning wave. Thus, the hot zone is moved as a front or thermal wave from the input well region through the preheated formation toward the output well. During the operation, or as part of a coordinated cycle, the temperature level is maintained in the frontal zone by controlling the oxygen content of the input gas with water, recycle flue gas or other substantially inert diluents.

A principle behind the moving thermal front formation is the reduction of the fuel content of the input gas stream to a proportion below the explosive limit so that the mixture cannot ignite until it is in the formation where unburned carbonaceous matter is available to enrich the fuel-oxygen ratio to within combustible limits and where a high enough temperature for spontaneous combustion exists. As injection of the cool oxygen-containing gas proceeds, regions in the stratum closer to the input well are cooled while regions remote from the heated passageway may be successively heated to 700° F., a temperature sufficient to fluidify and remove a quantity of the hydrocarbons present therein and to increase the cross-sectional area of the portions of the heated passageway remote from the input well. A carbonaceous residue is left in the passageway as fuel for combustion when the residue is contacted with the oxygen-containing gas.

In order to accomplish continuous forward movement of the heated zone as a wave of relatively narrow profile and high peak temperature, it is advantageous to move the zone into the formation by use of a relatively cool gas drive system. Alternate cycles may be operated in which an inert gas mixture, for example, recycled flue gas substantially free of oxygen, may be employed as a cold gas drive to keep the burning zone confined to the moving front and to heat the formation in front of the burning wave. Usually the combustion supporting gas will contain about 1–25% by volume of free oxygen, preferably about 5–20%.

In certain circumstances, depending on the character of the crude hydrocarbons and the well spacing, a reverse burning wave procedure may be advisible. For example, where the input well is rather distant from the output well and where heating of portions of the formation results in the movement of great amounts of viscous crude to the hot passageway at a temperature below about 700° F. thus tending to cool and clog the passageway, it is feasible to conduct the burning wave in reverse, that is, to have it pass from the producing well back to the input well, as disclosed in the aforementioned U.S. Patent No. 2,793,696. This reverse-traveling wave front may be accomplished by heating the walls of the output well, after the creation of the hot passageway, to combustion temperature and passing combustion-supporting gas into the output well until combustion is established in the formation adjacent the output well. When combustion is thus established in the formation itself, injection of combustion supporting gas to the output well is discontinued while injection of this gas into the input well at a relatively high pressure and exhaustion of the waste and hydrocarbon-containing gases from the output well is established. The creation of the hot passageway can overcome some of the difficulties encountered with reverse-burning waves described in the above-mentioned patent. During the burning wave, the hot passageway will offer less resistance to the flow of combustion-supporting or waste gases and also will, partially at least, provide for hydrocarbon recovery in the part of the stratum near the input well which may be beyond the economic recovery limit of the reverse-wave treatment.

As mentioned previously, the greater proportion of gases pass through the previously heated passageway which is maintained at a temperature above the congealing temperature of the fluidified hydrocarbons. The gases carry with them the vaporized hydrocarbons to the production well. Liquid hydrocarbons also flow to this well and recovery from the well may be accomplished by any suitable means.

Sometimes it may be desirable to introduce cool combustion supporting gas and perhaps some fuel gas as well to the output well when a burning wave breaks through to the production well. Such a procedure serves to cool the production well and also perhaps to prevent combustion of liquid hydrocarbons which have drained to the production well bottom hole. The cooling of the production well is desirable to prevent destruction of equipment in the production well and the plugging of the bore hole or equipment by coke and soot accumulation. Water may also be injected into the output well to control combustion and also, by partially filling the bottom hole, to prevent pressure escape to other parts of the field.

It is thus seen that the initial heating method of this invention removes hydrocarbons from an underground deposit containing hydrocarbons in a substantially nonflowable condition while minimizing heat losses and gas pressure requirements. For example, when applied to shale or a Kansas field containing a crude oil of about 23° API and exhibiting an effective gas permeability of 3 md., the method of this invention gives better results than other secondary recovery methods. The process prepares the formation for treatment by subsequent gas sweep thermal recovery procedures. The latter procedures include more gas sweeping the preheated formation or sending a burning wave through the stratum.

It is claimed:

1. A method for establishing communication between two wells in an oil shale formation comprising fracturing in said formation at a first well to produce a vertical fracture system generating outwardly from the well, determining the orientation of said fracture system, and drilling a lateral bore from the main bore of the second well to intersect said fracture and establish communication between said first and second wells.

2. The method of claim 1 wherein said drilling of the lateral bore comprises drilling a lateral curved bore having a predetermined uniform radius of curvature from the main bore of the second well in a direction to intersect said fracture system until an approximately horizontal plane is reached utilizing a drilling structure including a flexible drill shaft, a drill bit, a reamer attached behind said bit and a universal joint connecting said shaft and drill bit, said reamer cutting the lateral curved bore a sufficient amount to prevent stabilization of said drill bit, said joint structure having an overall diameter less than the drill bit and being positioned closely adjacent to the drill bit in accordance with the equation $RC=L^2/2a$ wherein RC is said predetermined radius of curvature, L is the distance measured from the centerline of said joint structure to the centerline of said reamer both in the

plane of contact to the drilled lateral curved bore and *a* is the distance between the centerline of the reamed lateral curved bore and the centerline of the joint structure, said flexible drill pipe also being of a diameter less than the drill bit whereby during drilling the drill bit can first be deflected in the desired direction from the main bore by the deflecting tool to start the lateral bore and thereafter the joint will be permitted by the dimensional relationship thereof to the reamer, the cutting of the reamer bit, and the size of the flexible drill pipe to be forced to the low side of the lateral bore being drilled and the bit will be directed continuously in said desired direction without substantial deviation and toward the high side of the bore bottom to thereby "build angle" and produce the curved bore, and after said plane is reached replacing said reamer with a stabilizer and drilling a horizontal bore until said fracture system is intersected.

3. The method of claim 2 wherein a drilling fluid containing an extreme pressure lubricant is circulated through said flexible shaft and around said drill bit during said drilling.

4. The method of claim 2 wherein an axial load in excess of 7,000 pounds is applied on said drilling structure.

5. A method for establishing communication between two wells in an underground petroliferous formation having an effective permeability less than about 10 millidarcies comprising fracturing in said formation at a first well to produce a vertical fracture system generating outwardly from the well, determining the orientation of said fracture system, and drilling a lateral bore from the main bore of the second well to intersect said fracture and establish communication between said first and second wells.

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JAMES A. LEPPINK, *Examiner.*

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Striegler et al.

[11] **3,960,214**

[45] **June 1, 1976**

[54] **RECOVERY OF BITUMEN BY STEAM INJECTION**

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[73] Assignee: **Atlantic Richfield Company**, Los Angeles, Calif.

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[51] **Int. Cl.^{2}** **E21B 43/24**; E21B 33/138

[58] **Field of Search** 166/272, 303, 271, 281, 166/285, 288, 50, 52, 256, 259; 175/62

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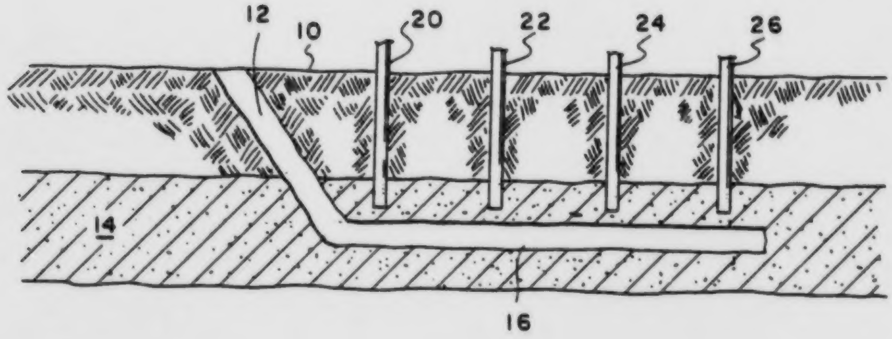
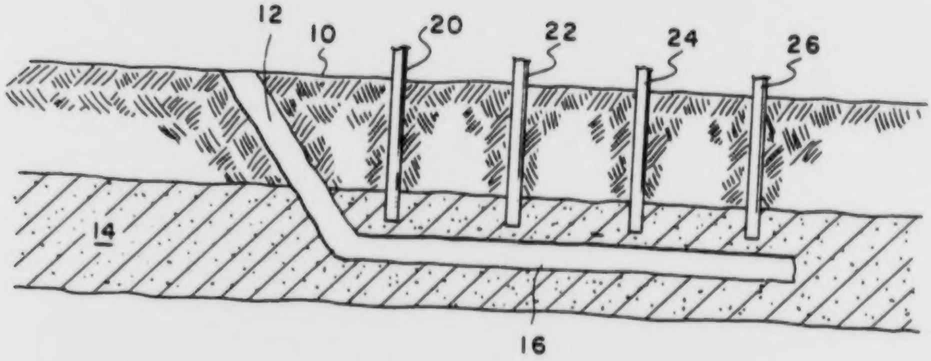
[57] **ABSTRACT**

A method of recovering bitumen from a subterranean tar sand formation by the following multi-step method. First, an injection well is drilled to the formation and cased. Perforations are provided in the portion of the injection well contacting the formation. Next, a plurality of production wells are drilled and completed into the formation positioned above and along the length of the injection well. Thereafter, a heated fluid is circulated through the injection well contacting the formation via the perforations and thereby reducing the viscosity of the bitumen contained therein rendering same mobile. Subsequently, the mobilized bitumen is recovered through the plurality of production wells.

6 Claims, 1 Drawing Figure





RECOVERY OF BITUMEN BY STEAM INJECTION

The prsent invention relates to the recovery of bitumen from a subterranean tar sand formation by means of fluid drive. More particularly it is concerned with the recovery of bitumen by steam injecton via a horizontal wellbore within the formation. The stream serves both as a driving agent to force the bitumen to the producton well and as a viscosity lowering agent to mobilize the bitumen over a substantial portion of the formation.

Large deposits of petroleum exist in the world which cannot be produced efficiently by conventional methods because of their extremely high viscosity. Such deposits include the Athabasca tar sands in Canada, the Jobo region in Venezuela, and the Edna and Sisquoc regions in California. In the Athabasca region alone upwards of 1500 billion barrels of oil may be present. Only a small portion of these tar sands are recoverable by surface mining techniques. It is all too clear that if these energy values are to be recovered for this generation and those to come they must be recovered by in situ techniques. Various proposals have been set forth for recovering the petroleum of the type contemplated herein. Some have involved steam injection, in-place combustion, etc., but none have been very successful as yet. The well-known huff-and-puff process, for recovering petroleum in which steam is injected into a formation for a period of time after which the steam-saturated formation is allowed to soak for an additional interval prior to placing the well on production, has too much of a time lapse before production is obtained. One of the principle reasons for the lack of success of previously attempted steam injection techniques for recovering bitumen from a tar sand formation has been the difficulty in providing a permeable, competent communications path or zone connecting injection wells and production wells. The present invention provides a method for overcoming these previously encountered problems in recovering bitumen from tar sands.

It is therefore an object of our invention to provide a process by which heat can be applied to a large volume of the tar sand formation while a heated fluid is simultaneously used to force the bitumen of reduced viscosity from the tar sand formation to the production well. It is a particular object of our invention to provide a method of recovering bitumen from a subterranean tar sand formation via a wellbore extending into said formation. It is another object of our invention to recover bitumen from a subterranean tar sand formation by circulating a heated fluid through a wellbore within said formation in fluid connection with a plurality of production wells positioned in said formation above and extending along said wellbore.

These and other objects will become apparent from the descriptive matter hereinafter, particularly when taken in conjunction with the figure.

In accordance with the present invention, bitumen is recovered from a subterranean tar sand formation by the following multi-step method. First, an injection well is drilled to the formation and extended into the formation and cased. Perforations are provided in the portion of the injection well in contact with the formation. Next, a plurality of production wells are drilled and completed into the formation positioned above and along the length of the injection well. Thereafter, a heated fluid is circulated through the injection well contacting the formation via the perforations and thereby reducing the viscosity of the bitumen contained therein rendering the bitumen mobile. Subsequently, the mobilized bitumen is recovered through the plurality of production wells.

The FIGURE illustrates a vertical section of a subterranean tar sand formation penetrated by a horizontally deviated injection well and a plurality of production wells positioned above and along said injecton well.

Referring to the figure, the drawing illustrates the earth's surface 10 from which a wellbore having a first section 12 has been drilled to penetrate a subterranean tar sand formation 14 and having a horizontal section 16 extending a desired distance therethrough. The drawing further shows wellbores 20 through 26 drilled and completed to penetrate the subterranean tar sand 14 and positioned above and along said horizontal section 16 of wellbore 12.

In carrying out an embodiment of the present invention and referring to the FIGURE, we have a cased, single-ended wellbore having a first section 12 and horizontal section 16 penetrating the subterranean tar sand formation 14. Initially, first section 12 is drilled to penetrate the tar sand formation 14 and horizontal section 16 is provided for a suitable distance into said formation. The injection well is then cased and perforations provided where it is in contact with the formation. Subsequently, vertical wellbores 20 through 26 are drilled and and completed to penetrate the subterranean tar sand formation 14 and positioned above and along, at suitable intervals, said horizontal section 16. After completion of drilling, circulation of a heated fluid such as stream or hot water is begun through the injection well contacting the formation via the perforations. The circulation, initially, of heated fluid is done at such pressures to cause breakthrough into wellbores 20 through 26 for fluid communication therewith. As the heated fluid is circulated through said single-end wellbore and contact is made with the formation via the perforations, the temperature of the formation is raised and the bitumen contained therein is rendered mobile. The mobilized bitumen is recovered by the driving force of the circulating fluid. After initial breakthrough to the wellbores 20 through 26, said wellbores are plugged back to a shallower depth in the tar sand away from horizontal section 16 and circulation of heated fluid is continued. In the operation of our invention, care should be taken in correlating the fluid composition, the fluid flow rate and the rate at which the fluid temperature is raised above the reservoir temperature, so that an adequate rate of flow is maintained at pressures that remain below the fracturing pressure of said formation.

The diameter and length of the injection well is not critical and will be determined by conventional drilling criteria, the characteristics of the specific formation, and the economics of a given situation. The diameter of the production wells is not critical and will be determined by conventional drilling criteria, etc. The production wells, however, must at least extend from the surface into the tar sand formation. The optimum number of and distance between production wells is a balance of econonmic criteria. Perforation size will be a function of other factors such as flow rate, temperature and pressures employed in a given operation. However, the injection well, in order to most efficiently exploit the effects of gravity in recovering the bitumen, should be extended into the formation at a positon near the bottom thereof.

Having thus described the invention, it will be understood that such description has been given by way of illustration and not by way of limitation, reference for the latter purpose being had to the appended claims.

Therefore, we claim:

1. Method of recovering bitumen from a subterranean tar sand formation containing bitumen which comprises:

drilling and completing an injection well to said formation and extending same into said formation, casing said injection well;

drilling and completing a plurality of production wells into said formation positioned above and along the length of said injection well;

perforating the portion of said cased injection well in contact with said formation, circulating a heated fluid through said injection well contacting said formation via said perforations and thereby reducing the viscosity of said bitumen contaned therein;

recovering said bitumen of reduced viscosity via said production wells.

2. The method of claim 1 wherin said injection well is extended into said formation near the bottom of same.

3. The method of claim 1 wherein said heated fluid is steam.

4. The method of claim 1 wherein said heated fluid is hot water.

5. The method of claim 1 wherein said heated fluid is circulated at a pressure to provide fluid communication between said injection well and production wells.

6. The method of claim 5 wherein subsequent to achieving said fluid communication, circulation of said heated fluid is stopped and said production wells are plugged back to a shallower depth in said formation and then circulation of heated fluid is resumed.

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United States Patent [19]

Striegler et al.

[11] **4,007,788**

[45] **Feb. 15, 1977**

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[54] **RECOVERY OF BITUMEN FROM TAR SANDS**

[75] Inventors: **John Howard Striegler**, Richardson; **Eddie Paul Howell**, Plano, both of Tex.

[73] Assignee: **Atlantic Richfield Company**, Los Angeles, Calif.

[22] Filed: **June 6, 1975**

[21] Appl. No.: **584,515**

[52] **U.S. Cl.** **166/272; 166/52**
[51] **Int. Cl.^{2}** **E21B 7/04; E21B 43/24**
[58] **Field of Search** 166/256, 259, 271, 272, 166/281, 285, 288, 303, 50, 52; 175/62

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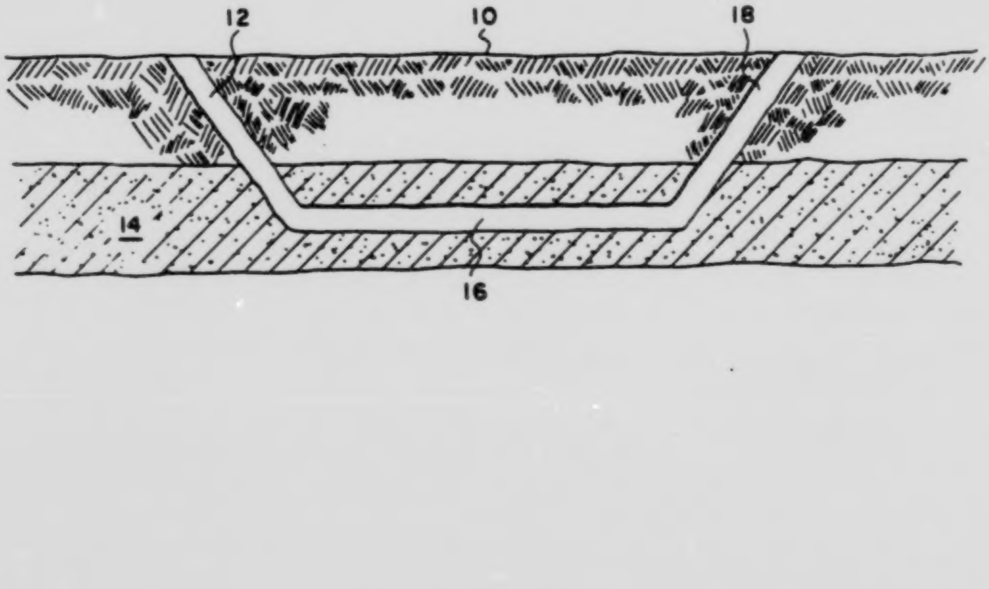
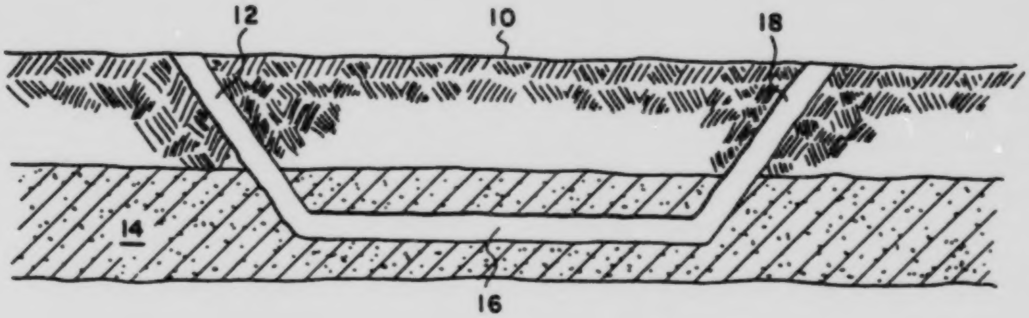
Primary Examiner—Stephen J. Novosad
Assistant Examiner—George A. Suchfield
Attorney, Agent, or Firm—Ronnie D. Wilson

[57] **ABSTRACT**

A method of recovering bitumen from a subterranean tar sand formation characterized by a plurality of steps. First, a continuous wellbore having a second section thereof contained within the formation and first and third sections thereof extending the second section to the earth's surface is formed. Next, the first and third sections of the wellbore are cased. Thereafter, a heated fluid is circulated through the wellbore contacting the formation to reduce the viscosity of the bitumen contained therein rendering the bitumen mobile. Subsequently, bitumen mobilized by the heated fluid is recovered via the wellbore.

1 Claim, 1 Drawing Figure





RECOVERY OF BITUMEN FROM TAR SANDS

The present invention relates to the recovery of bitumen from a subterranean tar sand formation by means of a fluid drive. More particularly it is concerned with the recovery of bitumen by steam injection via a continuous horizontal wellbore within the formation. The steam serves both as a driving agent to force the bitumen to the production well and as a viscosity lowering agent to mobilize the bitumen over a substantial portion of the formation.

Large deposits of petroleum exist in the world which cannot be produced efficiently by conventional methods because of their extremely high viscosity. Such deposits include the Athabasca tar sands in Canada, the Jobo region in Venezuela, and the Edna and Sisquoc regions in California. In the Athabasca region alone upwards of 1500 billion barrels of oil may be present. Only a small portion of these tar sands are recoverable by surface mining techniques. It is all too clear that if these energy values are to be recovered for this generation and those to come they must be recovered by in situ techniques. Various proposals have been set forth for recovering the petroleum of the type contemplated herein. Some have involved steam injection, in-place combustion, etc., but none have been very successful as yet. The well-known huff-and-puff process, for recovering petroleum in which steam is injected into a formation for a period of time after which the steam-saturated formation is allowed to soak for an additional interval prior to placing the well on production, has too much of a time lapse before production is obtained. One of the principle reasons for the lack of success of previously attempted steam injection techniques for recovering bitumen from a tar sand formation has been the difficulty in providing a permeable, competent communication path or zone connecting injection wells and production wells. The present invention provides a method for overcoming these previously encountered problems in recovering bitumen from tar sands.

It is therefore an object of the present invention to provide a process by which heat can be applied to a large volume of a tar sand formation while simultaneously forcing the bitumen of reduced viscosity from the formation to production. It is a particular object of the present invention to provide a method for recovering bitumen from a subterranean tar sand formation via a continuous wellbore in the formation. It is another object of our invention to recover bitumen from a subterranean tar sand formation by circulating a heated fluid through a wellbore in said formation having both end sections thereof cased and extending to the surface.

These and other objects will become apparent from the descriptive matter hereinafter, particularly when taken in conjunction with the FIGURE.

In accordance with the present invention, bitumen is recovered from a subterranean tar sand formation by the following multi-step method. First, a continuous wellbore having a second section thereof contained within the formation and first and third sections thereof extending said second section to the earth's surface is formed. Next, the first and third sections of the wellbore are cased. Thereafter, a heated fluid is circulated through the continuous wellbore contacting the formation to reduce the viscosity of the bitumen contained therein. Subsequently, bitumen mobilized by the heated fluid is recovered via the wellbore.

The figure illustrates a vertical section of a subterranean tar sand formation penetrated by a continuous wellbore having both ends thereof extending to the surface of the earth.

Referring to the figure, the drawing illustrates the earth's surface 10 from which a wellbore's first section 12 has been drilled by well-known means to penetrate a subterranean tar sand formation 14 and having a second section 16 extending therethrough and turning upward at third section 18 to the earth's surface. Wellbore sections 12 and 18 are cased.

In carrying out an embodiment of the present invention and referring to the figure, we have a continuous wellbore having first and third sections 12 and 18 and second section 16 penetrating the subterranean tar sand formation 14. Initially, first section 12 of the wellbore is drilled to penetrate the tar sand formation 14 and the section is cased. Subsequently, a second section 16 and third section 18 are drilled providing a continuous wellbore extending through the formation. The drill pipe utilized for the wellbore is then withdrawn into second section 16 from third section 18 in order that the casing of third section 18 may take place. After casing third section 18, injection of a heated fluid such as steam or hot water is begun via first section 12 of the continuous wellbore. While injecting a heated fluid, the drill pipe is withdrawn from the second section 16 to the surface 10 at such a rate that to prevent plugging i.e. if the hole is sloughed it is filled with clean sand so as not to interrupt the drive provided by the heated fluid. As the heated fluid is circulated through the continuous wellbore, the temperature of the tar sand formation is raised and the bitumen contained therein rendered mobile. The mobilized bitumen is recovered via third section 18 by the driving force of the circulating heated fluid. In the operation of the present invention, care should be taken in correlating the fluid composition, the fluid flow rate and the rate at which the fluid temperature is raised above the reservoir temperature, so that an adequate rate of flow is maintained at pressures that remain below the fracturing pressure of the formation.

The diameter and length of the continuous wellbore is not critical and will be determined by conventional drilling criteria, the characteristics of the specific formation, and the economics of a given situation. In order to most efficiently exploit the effects of gravity in recovering the bitumen, the second section of the wellbore should be formed near the bottom of the tar sand formation.

Having thus described the invention, it will be understood that such description has been given by way of illustration and not by way of limitation, reference for the latter purpose being had to the appended claims.

Therefore, we claim:

1. Method of recovering bitumen from a subterranean tar sand formation containing bitumen which comprises:

forming a continuous wellbore having a second section contained within said formation and first and third sections extending said second section to the earth's surface,

casing said first and third sections of said wellbore whereby said second section is open to said formation, circulating a heated fluid via said first section through said wellbore contacting said formation and reducing the viscosity of said bitumen contained therein to render said bitumen mobile while withdrawing means whereby said wellbore is

formed at a rate to prevent plugging of said second section, and

recovering said mobilized bitumen via said third section of said wellbore.

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Alberta OIL SANDS INFORMATION CENTER 06435

United States Patent [19]

Pasini, III et al.

[11] **4,062,404**

[45] **Dec. 13, 1977**

[54] **METHOD FOR IN SITU COMBUSTION**

[75] Inventors: **Joseph Pasini, III; Lowell Z. Shuck; William K. Overbey, Jr.**, all of Morgantown, W. Va.

[73] Assignee: **The United States of America as represented by the United States Energy Research and Development Administration**, Washington, D.C.

[21] Appl. No.: **728,358**

[22] Filed: **Sept. 30, 1976**

[51] **Int. Cl.²** **E21B 43/24; E21B 43/26**

[52] **U.S. Cl.** **166/259**; 166/50; 166/52; 166/251

[58] **Field of Search** 166/259, 251, 256, 245, 166/50, 52, 272

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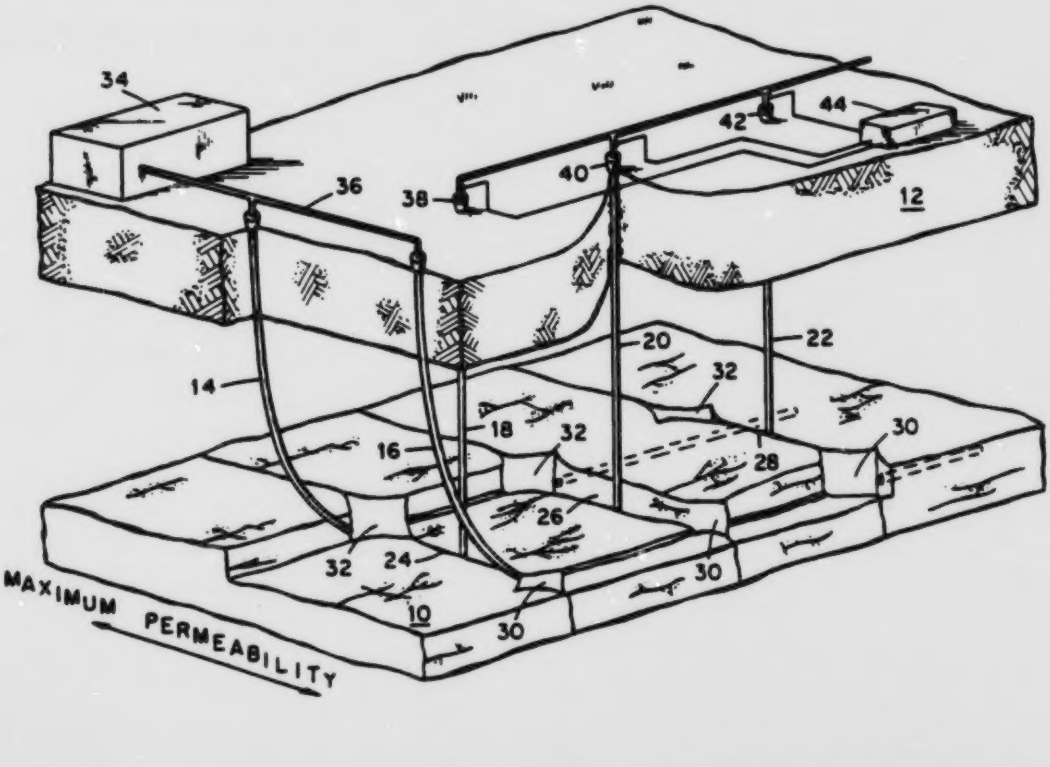
Primary Examiner—Stephen J. Novosad

Attorney, Agent, or Firm—Dean E. Carlson; Stephen D. Hamel; Earl L. Larcher

[57] **ABSTRACT**

This invention relates to an improved in situ combustion method for the recovery of hydrocarbons from subterranean earth formations containing carbonaceous material. The method is practiced by penetrating the subterranean earth formation with a borehole projecting into the coal bed along a horizontal plane and extending along a plane disposed perpendicular to the plane of maximum permeability. The subterranean earth formation is also penetrated with a plurality of spaced-apart vertical boreholes disposed along a plane spaced from and generally parallel to that of the horizontal borehole. Fractures are then induced at each of the vertical boreholes which project from the vertical boreholes along the plane of maximum permeability and intersect the horizontal borehole. The combustion is initiated at the horizontal borehole and the products of combustion and fluids displaced from the earth formation by the combustion are removed from the subterranean earth formation via the vertical boreholes. Each of the vertical boreholes are, in turn, provided with suitable flow controls for regulating the flow of fluid from the combustion zone and the earth formation so as to control the configuration and rate of propagation of the combustion zone. The fractures provide a positive communication with the combustion zone so as to facilitate the removal of the products resulting from the combustion of the carbonaceous material.

4 Claims, 3 Drawing Figures



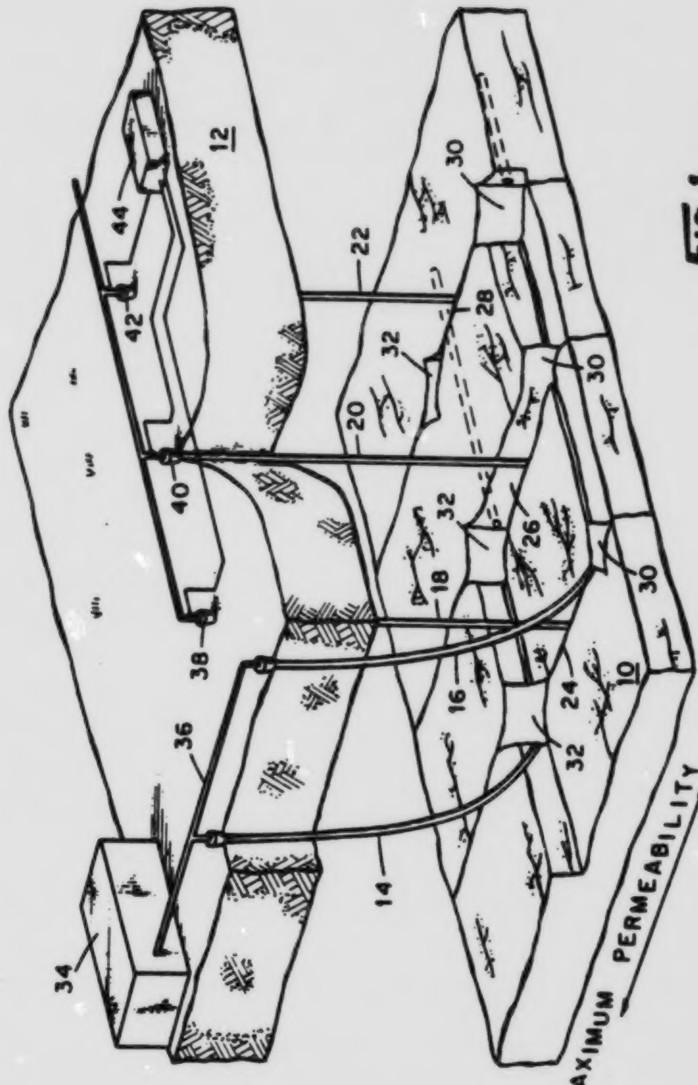

MAXIMUM PERMEABILITY

Fig. 1

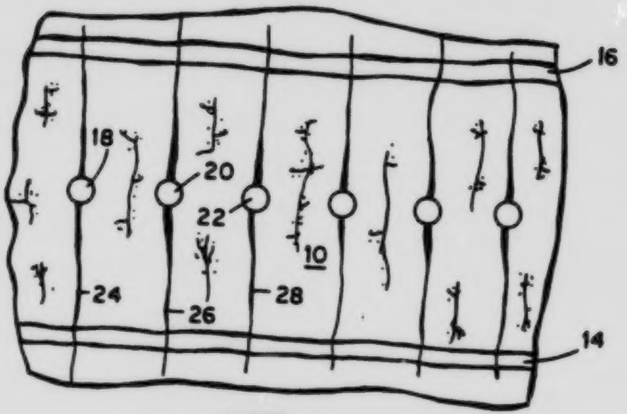

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Fig. 2

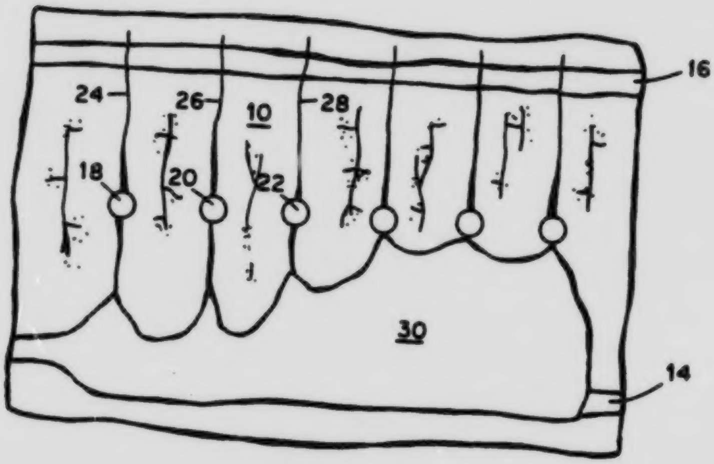
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Fig. 3

METHOD FOR IN SITU COMBUSTION

The present invention relates generally to the recovery of hydrocarbons from subterranean earth formations and, more particularly, to an improved method of in situ combustion of such formations wherein the combustion zone propagates through the earth formations at selectively controlled rates and configurations.

The recovery of hydrocarbons from underground strata containing carbonaceous material by in situ combustion processes is becoming of increasing importance in the effort to satisfy the energy needs of the world. The in situ combustion is initiated in the carbonaceous material and the resulting combustion zone is caused to move through the stratum by either a reverse or direct burn. The heat of combustion gasifies the carbonaceous material to provide gaseous hydrocarbons and also displaces hydrocarbon material from the stratum so as to provide a recoverable source of fluid (gas and liquid) which contains considerable energy values. Several variables are associated with in situ combustion processes which determine operating parameters. For example, in a conventional forward or reverse burn in situ combustion process the underground stratum is penetrated by boreholes set at spaced-apart locations with the spacing being determined by such factors as the allowable air (combustion supporting medium), injection pressure, the air velocity in the stratum, the permeability of the underground earth formation containing the carbonaceous material, and the particular type of earth formation containing the recoverable hydrocarbons. Such in situ combustion techniques as presently known may be used to recover hydrocarbons in the form of fluids, such as petroleum from tar sands, oil sands, and shale, and high and low Btu gases from subterranean coal beds.

In the recovery of liquid hydrocarbon products by employing conventional forward burn in situ combustion operations the combustion zone propagates from a point near the face of an air injection well towards a production well so as to displace the viscous hydrocarbons towards the production well where the product is recovered. However, there has been found to be several problems attendant with the use of in situ combustion for this purpose. For example, the liquid hydrocarbon is of a relatively low viscosity near the combustion zone but substantially increases in viscosity as it cools and nears the production well so as to present considerable difficulty in displacing the liquid through the underground strata for subsequent removal at the production well. In fact, the resistance to flow of the liquid hydrocarbons through the reservoir eventually becomes so great that the combustion process becomes somewhat restricted due to the lack of a suitable discharge for the combustion products.

In the recovery of gaseous hydrocarbons from subterranean coal beds by the gasification of the coal the products of the forward burn combustion process flow through the coal bed to the producer well where the gaseous product is withdrawn. The control of the combustion zone with respect to its configuration and rate of propagation through the subterranean coal bed presents some problems in that these operating parameters must be carefully controlled so as to maintain the Btu content of the gas at an acceptably high level and also insure that the combustion zone advances through the coal bed in such a manner that essentially all available coal lying between the injection well and the producer well is gasified. Frequently, the combustion zone propagates between the injection well and the producer well along an irregular and uncontrolled path such that the burn front of the combustion zone reaches the producer well without contacting a substantial quantity of the coal lying therebetween. This problem due to irregular and uncontrolled combustion zone propagation considerably detracts from the overall efficiency and desirability of the in situ combustion processes. These problems due to lack of control over the combustion zone configuration and rate of propagation are also present in in situ combustion processes used for the recovery of liquid hydrocarbons from earth strata containing burnable and displaceable carbonaceous material such as mentioned above.

Several efforts have been previously made to insure that essentially all the coal or other carbonaceous material lying between the injector well and the producer well is subjected to the combustion process so as to efficiently recover the hydrocarbons in the carbonaceous material. One such effort is disclosed in assignee's U.S. Pat. No. 3,933,447 which issued Jan. 20, 1976, and is entitled "Underground Gasification Of Coal" by Joseph Pasini III et al. This patent teaches that efficient gasification of an underground coal bed may be achieved by penetrating the coal bed with spaced-apart directionally drilled boreholes which project along a horizontal plane within the coal bed that extends in a direction normal to the plane of maximum permeability. The combustion of the coal is initiated at one of these horizontal boreholes and the product gas is removed from the producer borehole which spaced the combustion along the plane of maximum permeability. The combustion process in this patent is enhanced by utilizing the natural fracture system extending between the injection borehole and the producer borehole to assure the propagation of the combustion zone therebetween as well as to enhance the removal of the product gas. It is further contemplated in this patent to induce fractures in the coal bed extending between the boreholes so as to further enhance the removal of the product gas and increase the efficiency of the combustion operation.

While the combustion process described in assignee's aforementioned patent represents a substantial advancement in the field, there were still several factors present which detracted from the overall efficiency of the process. For example, the presence of non-uniform permeability in the coal bed lying between the injector borehole and the producer borehole due to such conditions as excessive natural fractures or other anomalies in a portion of the coal bed or the non-uniformity of the induced fractures could cause the combustion zone to propagate at an excessive rate in that portion of the coal bed. Further, in the event such non-uniform propagation of the combustion zone occurred in one portion of the coal bed there was no mechanism for controlling the combustion zone configuration such as by slowing the rate of propagation in this portion of the coal bed or by increasing the burn rate in other portions of the coal bed so as to provide a more uniform and efficient gasification process.

Accordingly, it is the primary aim or goal of the present invention to provide an in situ combustion process for recovering hydrocarbons from a subsurface strata containing carbonaceous material that represents an improvement over the process described in the aforementioned patent as well as other processes known in the art. Generally, the subject in situ combustion process is practiced by the steps of penetrating the earth formation with at least one borehole projecting into the earth formation along a substantially horizontal plane with respect to the earth surface and along a plane substantially perpendicular to the plane of maximum permeability in the earth formation. Penetrating the earth formation with a plurality of vertically extending boreholes with these boreholes spaced apart from one another along a plane substantially parallel to the horizontal borehole. Providing an induced fracture in the earth formation at each of the plurality of vertical boreholes along a plane substantially parallel to the plane of maximum permeability and intersecting with the horizontal borehole for establishing a plurality of fluid flow paths which extend between the horizontal borehole and the plurality of vertical boreholes. Combustion is initiated in the carbonaceous material adjacent to the horizontal borehole to form a combustion zone. Hydrocarbon-containing fluid resulting from or displaced by the combustion of the carbonaceous material is withdrawn through the plurality of vertical boreholes primarily via the fluid flow paths provided by the fractures with the rate of flow of the fluid through each of the plurality of vertical boreholes being controlled for selectively controlling the configuration and rate of propagation of the combustion zone. By practicing the method of the present invention, the necessary controls are provided over the combustion zone configuration and rate of propagation to insure that, if desired, all portions of the carbonaceous material lying between the horizontal borehole and the vertical boreholes may be subjected to combustion. Further, the presence of the induced fractures extending from the combustion zone to the flow-controlled vertical boreholes provides a conduit for efficiently conveying both liquid and gaseous hydrocarbons to points of recovery, i.e., the vertical boreholes.

Other and further objects of the invention will be obvious upon an understanding of the illustrative method about to be described or will be indicated in the appended claims, and various advantages not referred to herein will occur to one skilled in the art upon employment of the invention to practice.

An embodiment of the invention has been chosen for the purpose of illustration and description of the method disclosed and claimed herein. The embodiment illustrated is not intended to be exhaustive or to limit the invention to the precise method steps disclosed. It is chosen and described in order to best explain the principles of the invention and their application in practical use to thereby enable others skilled in the art to best utilize the invention in various embodiments and modifications of the method as are best adapted to the particular use contemplated.

In the accompanying drawings:

FIG. 1 is a schematic perspective view showing a subsurface earth formation containing carbonaceous material which is provided with the borehole and fracture system in accordance with the practice of the subject method;

FIG. 2 is a schematic plan view showing the borehole and fracture orientation of the FIG. 1 embodiment with a greater number of vertical boreholes prior to combustion; and

FIG. 3 is a schematic plan view similar to FIG. 2, but showing various schemes of controlled combustion which may be achieved by practicing the subject method.

With reference to FIGS. 1-3 of the accompanying drawings, the method of the present invention for recovering hydrocarbons from subsurface earth formations containing carbonaceous material by employing in situ combustion procedures may be practiced by employing the illustrated drilling and fracturing scheme. As shown in FIG. 1, subterranean earth formation 10 containing carbonaceous material is disposed at some level below one or more layers of overburden 12. A directional borehole 14 is drilled from the surface of the overburden 12 on a slant so as to penetrate the subterranean strata containing the carbonaceous material along a substantially horizontally oriented path with respect to the subterranean strata 10 or the surface of the overburden 12. The borehole 14 is drilled in this horizontal direction and perpendicular to the plane of maximum permeability in the strata 10 either continuously from the surface through the strata 10 and back to the surface or into the strata 10 and terminating at some location therein. The drilling of the borehole 14 to provide the horizontal orientation of the latter within the subterranean earth strata 10 may be initiated at any angle from vertical at the surface with this angle depending upon the depth of the coal bed and the type of the drilling equipment employed. In any event, the drilling procedure should be such that when the borehole 14 enters the carbonaceous strata 10 it is traveling in a substantially horizontal direction so as to penetrate a desired portion of the subterranean earth formation strata 10. The use of such a horizontal borehole substantially minimizes the number of well bores necessary to contact a relatively large segment of the subsurface earth strata 10. Further details relating to the drilling of the horizontal borehole 14 are set forth in the aforementioned patent. Borehole 14 extends horizontally within the subsurface earth strata along a plane oriented substantially perpendicular to the plane of maximum permeability which is also substantially perpendicular to the plane of maximum tetonic compressive stress. Preferably, the subterranean earth formation is penetrated with one or more additional horizontal boreholes similar to borehole 14, such as shown at 16, with these horizontal boreholes being parallel to and separated from one another a selected distance in the range of about 200 to 1000 feet depending upon the particular characteristics of the subterranean strata 10. With boreholes 14 and 16 projecting through the strata 10 along a plane perpendicular to the plane of maximum permeability, the maximum fluid flow through the strata is along planes extending between these boreholes 14 and 16.

In accordance with the practice of the present invention a plurality of vertically extending boreholes are drilled into the subsurface earth strata 10 at locations spaced from a single horizontal borehole such as 14 or intermediate a plurality of such boreholes as 14 and 16. These vertical boreholes, as shown at 18, 20 and 22, penetrate the subsurface earth strata 10 and are spaced from one another along a plane generally parallel to that of the boreholes 14 and 16. The spacing of the vertical boreholes 18, 20 and 22 from each other and the boreholes 14 and 16 is largely dependent upon the particular subsurface earth formation in which the boreholes penetrate and upon the type of hydrocarbon recovery operation to be employed.

After the subsurface earth strata 10 is provided with the boreholes 14, 16, 18, 20 and 22 a vertical fracture is then induced in the subsurface earth strata 10 at each vertical borehole 18, 20 and 22. These fractures may be induced in the subsurface earth strata 10 by employing any well known hydraulic, explosive, or pneumatic technique as commonly practiced in the art. Since it is known that the directional characteristics of the fracture system are dictated by the orientation or the maximum tetonic compressive stress field and since this field is at least generally parallel the plane of maximum permeability, the fractures 24, 26 and 28 induced at the well bores 18, 20 and 22, respectively, can be extended from the vertical boreholes generally along the plane of maximum permeability so as to intersect the horizontal boreholes 14 and 16 and thereby placing the latter in fluid flow registry with each of the vertical boreholes.

Upon completion of the drilling and fracturing steps, combustion may be initiated in any suitable well-known manner at either of the boreholes 14 or 16 so as to provide a combustion zone at the points where each fracture intersects therewith or, if desired, over the entire length of the boreholes 14 and 16 within the strata 10. The combustion-supporting medium, e.g., air, or oxygen-rich air, is injected into the subsurface earth strata 10 from a suitable source, such as shown at 34, through a conduit system 36 coupled to the boreholes 14 and 16. With the combustion-supporting gas entering the injection bores 14 and 16 the combustion zone or zones, as shown at 30 and 32, propagate through the subsurface earth formation in a controlled forward burn manner via the fracture system to the producer wells 18, 20 and 22.

In order to control the configuration and rate of propagation of the combustion zone, each of the vertical boreholes 18, 20 and 22 are provided with flow control valves at the wellhead thereof, such as indicated at 38, 40 and 42, respectively. These valves are selectively operable to control the rate of flow and thus the extraction of the combustion products from the combustion zone and the displaced fluids from the strata through each borehole 18, 20 and 22. This control of the flow of combustion products and other fluids from the subterranean strata 10 may be achieved by employing a suitable monitoring system, as generally shown at 44, which may be used to analyze and control the flow rate by the rate of product flow through each of the vertical boreholes and/or by the composition and viscosity of the product fluid.

By selectively controlling the flow rate of the fluids from the strata 10 due to the presence of combustion zones 30 and 32 through the producer wells 18, 20 and 22, the combustion process, the rate of burn front propagation and the configuration of the combustion zone or zones in the subterranean earth formation may be closely regulated so as to efficiently combust the entire or selected portions of the earth formation lying between the injector wells and the producer wells. Further, by employing the vertical fracture system 24, 26 and 28 between the injector wells and the producer wells, the products resulting from the combustion of the carbonaceous materials are provided with relatively open conduits for facilitating the recovery of fluids from the subterranean earth formation.

As best shown in FIG. 3, the general configuration or layout of the boreholes and the fracture system greatly facilitates the control over the combustion zone so as to assure efficient recovery of the hydrocarbons in the subterranean earth formations. For example, the particular orientation of the combustion zone can be regulated by the selective control of the valved wellheads on the vertical boreholes so that the combustion zone may uniformly propagate across the entire earth formation between the horizontal injector wells 14 or 16 to the producer wells 18, 20 and 22. Alternatively, if it is desirable to selectively combust segments or blocks of the subterranean earth formation 10, the flow through one or more of the vertical boreholes may be substantially reduced while increasing the flow at one or more of adjacent boreholes, 18, thus allowing the combustion process to proceed more rapidly through the subterranean earth formation in segments contiguous to and intermediate the fracture in registry with the boreholes with the greatest flow.

It will be seen that the present invention provides an improved in situ combustion process for the recovery of hydrocarbons from subterranean earth formations wherein the flow of the combustion products and hydrocarbons released and recoverable from the earth formation is in a manner substantially more efficient than previously obtainable. Further, the induced fracture system provides relatively open communication between the vertical boreholes and the combustion zone as well as the earth formation therebetween for assuring that the products of combustion and the fluids released from earth formations due to the combustion process may be quickly and easily recovered so as not to impede the combustion process.

What is claimed is:

1. An improved method of in situ combustion of carbonaceous material in a subterranean earth formation for effecting the recovery of hydrocarbons, comprising the steps of penetrating the earth formation with a pair of boreholes projecting into the earth formation along a substantially horizontal plane with respect to the earth surface and along a plane substantially perpendicular to the plane of maximum permeability in the earth formation with said boreholes being parallel to and separated from one another along the plane of maximum permeability, penetrating the earth formation with a plurality of vertically extending boreholes with these vertical boreholes being spaced apart from one another along a plane substantially parallel to and intermediate said pair of boreholes, providing an induced fracture in said earth formation at each of the plurality of vertical boreholes along a plane substantially parallel to the plane of maximum permeability and intersecting with each of said pair of boreholes for establishing a plurality of fluid flow paths projecting between said pair of boreholes and said plurality of boreholes, introducing a combustion-supporting medium into said earth formation through at least one of said pair of boreholes, initiating combustion of the carbonaceous material adjacent to at least one of said pair of boreholes to form a combustion zone, withdrawing hydrocarbon-containing fluid resulting from or displaced by said combustion primarily via said fluid flow paths through said plurality of boreholes, and controlling the rate of flow of said fluid through each of said plurality of boreholes for selectively controlling the configuration and rate of propagation of said combustion zone.

2. An improved method of in situ combustion as claimed in claim 1, wherein the combustion of the carbonaceous material is initiated at each of said pair of boreholes projecting into the earth formation along a substantially horizontal plane.

3. An improved method of in situ combustion as claimed in claim 1, wherein said earth formation is petroleum-bearing sand or shale.

4. An improved method of in situ combustion as claimed in claim 1, wherein the earth formation is a coal bed.

* * * * *

1978

Alberta OIL SANDS INFORMATION CENTER 006445

United States Patent [19] [11] **4,085,803**

Butler [45] **Apr. 25, 1978**

[54] **METHOD FOR OIL RECOVERY USING A HORIZONTAL WELL WITH INDIRECT HEATING**

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[73] Assignee: **Exxon Production Research Company**, Houston, Tex.

[21] Appl. No.: **777,293**

[22] Filed: **Mar. 14, 1977**

[51] **Int. Cl.**² **E21B 43/24**

[52] **U.S. Cl.** **166/303**; 166/50; 166/57

[58] **Field of Search** 166/272, 303, 302, 256, 166/259, 50, 57, 60, 263; 299/2

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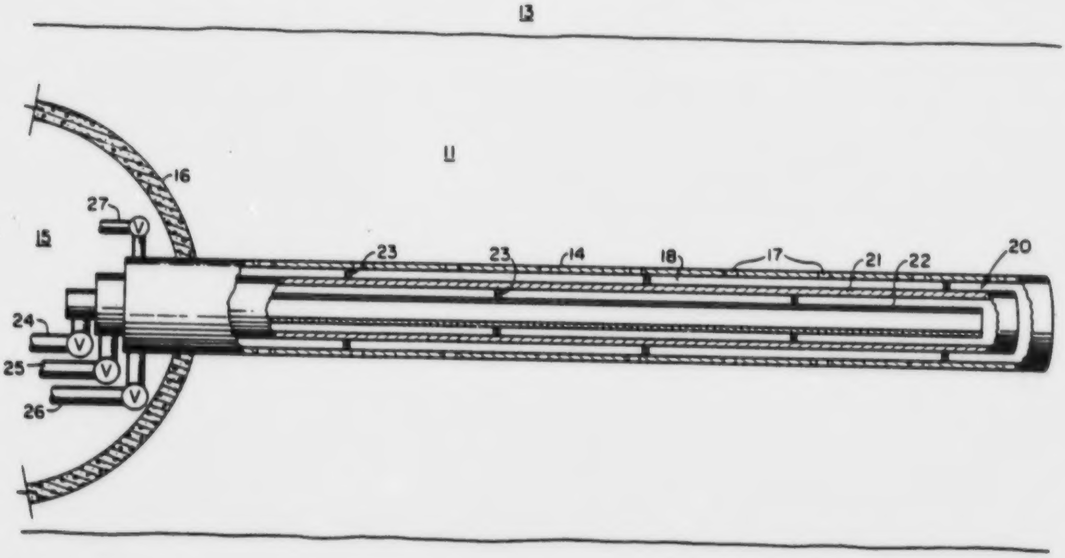
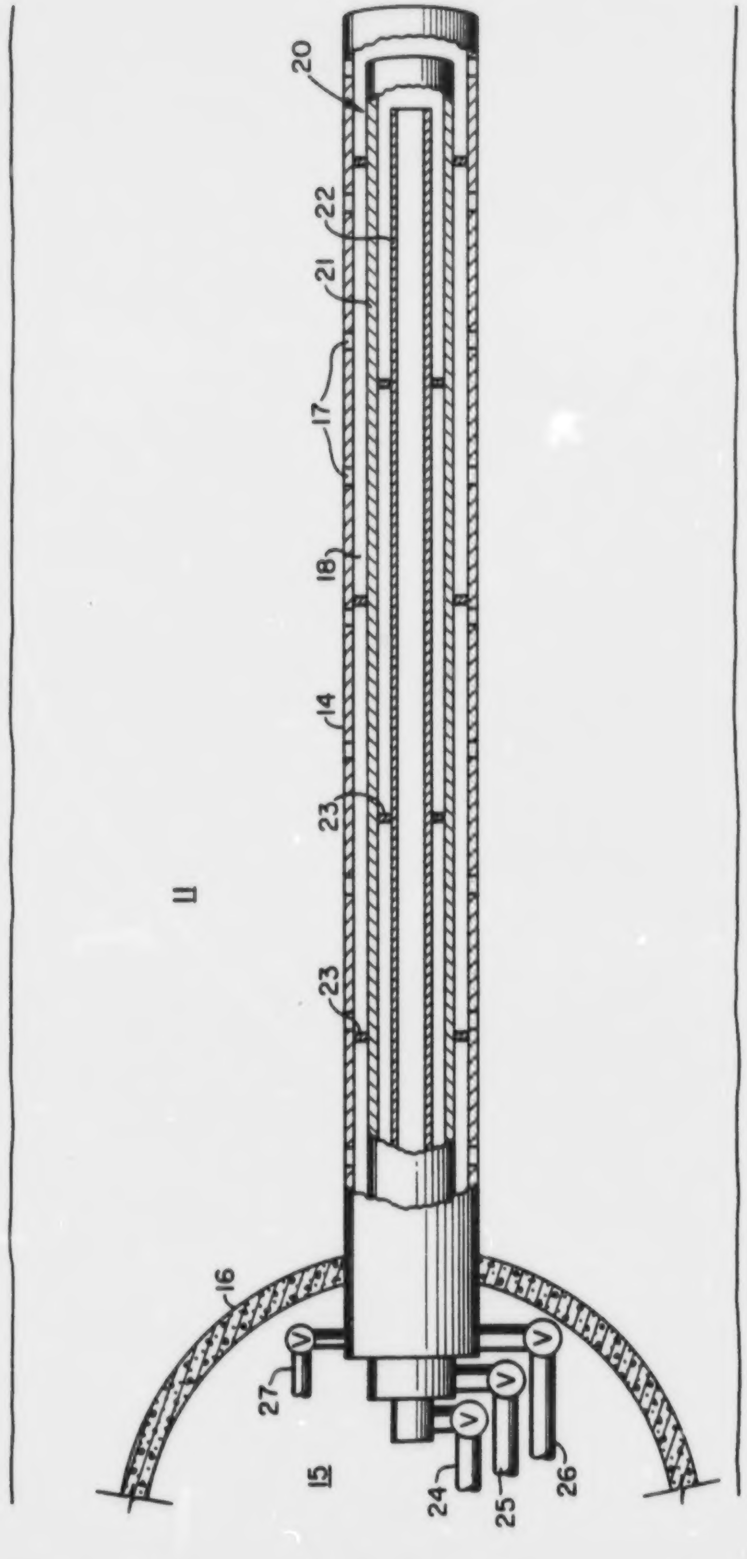
Primary Examiner—Stephen J. Novosad
Attorney, Agent, or Firm—Gary D. Lawson

[57] **ABSTRACT**

Disclosed is a method for recovering hydrocarbons from a subterranean formation. A heated fluid is injected into the formation by means of a perforated conduit which is positioned substantially horizontally through the formation to heat hydrocarbons within the formation. After a suitable heating period, injection of heat is terminated to permit fluids including formation hydrocarbons to drain from the formation into the conduit. The drained fluids within the conduit are then heated to a temperature such that at least a portion of the drained fluids are vaporized. These vaporized fluids pass from the perforated conduit and into the formation to further heat formation hydrocarbons. Subsequently, formation fluids of reduced viscosity are recovered from the formation through the perforated conduit.

16 Claims, 1 Drawing Figure





METHOD FOR OIL RECOVERY USING A HORIZONTAL WELL WITH INDIRECT HEATING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a process including a shaft or deep boring in the earth, commonly known as wells, for the extraction of fluids from the earth. More particularly, this invention relates to a process for recovering hydrocarbons from a subterranean formation using a well or wells for injection and production and including heating steps.

2. Description of the Prior Art

In many areas of the world, there are large deposits of viscous petroleum. Examples of viscous petroleum deposits include the Athabasca and Peace River regions in Canada, the Jobo region in Venezuela and the Edna and Sisquoc regions in California. These deposits are generally called tar sand deposits due to the high viscosity of the hydrocarbons which they contain. These tar sands may extend for many miles and may occur in varying thickness of up to more than 300 feet. Although tar sands may lie on or near the earth's surface, generally they are located under an overburden which ranges in thickness from a few feet to several thousand feet. The tar sands located at these depths constitute one of the world's largest presently known petroleum deposits.

The tar sands contain a viscous hydrocarbon material, which is generally referred to as bitumen, in an amount which ranges from about 5 to about 20 percent by weight. This bitumen is usually immobile at typical reservoir temperatures. For example, at reservoir temperatures of about 48° F, bitumen is immobile, having a viscosity frequently exceeding several thousand poises. At higher temperatures, such as temperatures exceeding 200° F, the bitumen becomes mobile with a viscosity of less than 345 centipoises.

In situ heating is among the most promising methods for recovering bitumen from tar sands because there is no need to move the deposit and because thermal energy can substantially reduce the viscosity of bitumen. The thermal energy may be introduced into the tar sands in a variety of forms. For example, hot water, in situ combustion, and steam have been suggested to heat tar sands. Although each of these thermal energy agents may be used under certain conditions, steam is generally the most economical and efficient.

Thermal stimulation processes are among the most promising of the in situ methods for heating tar sand formations. In one process, commonly referred to as the "huff and puff" process, steam is injected through a well and into a viscous hydrocarbon deposit for a period of time. The well is then shut in to permit the steam to heat the oil. Subsequently, the well is placed on production.

To accelerate the input of heated fluids into the formations, it has been proposed to drill horizontally deviated wells or to drill lateral holes outwardly from a main borehole or tunnel. Examples of various thermal systems using horizontal wells are described in U.S. Pat. Nos. 1,634,236, Ranney; 1,816,260, Lee; 2,365,591, Ranney; 3,024,013, Rogers et al.; 3,338,306, Cook; 3,960,213, Striegler et al.; 3,986,557, Striegler et al.; Canadian Pat. No. 481,151, Ranney; and German Pat. No. 1,163,750, Heuckeroth. However, injection of heated fluids into tar sand formation through horizontal wells has not been developed commercially. One difficulty with these prior art methods is that hydrocarbons do not flow into the horizontal well in economic quantities.

There is a substantially unfilled need for an improved thermal method for effectively recovering viscous hydrocarbons from subterranean formation.

SUMMARY OF THE INVENTION

In accordance with the practice of this invention, hydrocarbons are recovered from a subterranean formation by the following method. A heated fluid is injected into the formation by means of a perforated conduit which is disposed in a substantially horizontal manner within the formation to heat hydrocarbons within the formation and to render the hydrocarbons more flowable. Injection of the heated fluid is then terminated to permit formation fluids, including the heated formation hydrocarbons, to flow into the perforated conduit. Subsequently, formation fluids within the perforated conduit are heated to a temperature sufficient to vaporize at least a portion of said formation fluids to cause such vaporized fluids to pass from the perforated conduit into the formation. These vaporized fluids further heat the formation hydrocarbons to render the hydrocarbons more flowable. Heated formation fluids including heated formation hydrocarbons are then withdrawn from the formation by means of the perforated conduit.

In the practice of the preferred embodiment of this invention, a perforated conduit is extended substantially horizontally into a tar sand deposit from a tunnel which is disposed near the bottom of the tar sand deposit. Disposed in the perforated conduit are dual concentric conduits which comprise an inner conduit and a surrounding larger diameter intermediate conduit. The intermediate conduit and the perforated conduit cooperate to form an annular space and the inner conduit and the intermediate conduit cooperate to provide a continuous enclosed fluid flow path through the intermediate conduit. Steam and optionally a solvent is injected into the formation through the annular space to reduce the viscosity of formation hydrocarbons. After a suitable injection interval, formation fluids are permitted to drain into the annular space. Subsequently, steam or another heating medium is passed through the intermediate conduit to heat indirectly the drained fluids in the annular space. During this indirect heating, additional steam or hydrocarbon vapors are produced by boiling and these vapors pass into the surrounding reservoir heating and diluting the bitumen therein. After a suitable indirect heating period, formation hydrocarbons are drained from the annular space to the tunnel and are pumped through suitable conduits to a processing unit.

The practice of this invention enhances drainage of viscous hydrocarbon into the horizontal well. The invention will therefore be seen to offer significant advantages over conventional methods for recovering viscous hydrocarbons.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a vertical cross-sectional view illustrating a completion assembly for a horizontal conduit extending from a tunnel into a tar sand deposit.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the FIGURE, a description of the preferred embodiment of the method of this invention will be described in an unconsolidated tar sand formation. A subterranean formation 11 is shown which contains tar sands such as Athabasca tar sands, disposed below the earth's surface (not shown), beneath an overburden 13.

As the first step of this embodiment, a perforated conduit 14 is disposed in the tar sand deposit 11. The FIGURE illustrates a substantially horizontal conduit 14 which extends from a tunnel 15 which is positioned approximately transverse to the conduit 14. The tunnel wall 16 may be composed of any suitable material such as cement to prevent unrestricted fluid communication between the tunnel and the formation. The perforated conduit 14 is positioned through the tunnel wall and is sealed to the wall in any convenient manner to prevent unrestricted ingress of fluid into the tunnel. The perforated conduit 14 may be extended into the tar sands by any conventient means. For example, a wellbore may be drilled and a perforated liner may then be inserted into the well or the conduit may be driven into the formation with a vibrator. The art of forming tunnels in tar sands and of extending horizontal conduits from tunnels is well known.

The conduit 14 contains slots or perforations 17 to provide fluid communication between the interior of the conduit and the tar sand deposit. Inlet and outlet pipes 26 and 27 provide fluid communication into and out of the conduit 14. Disposed within the perforated conduit 14 is a heater assembly 20 which comprises dual concentric pipes 21 and 22. The pipe 21 extends substantially the entire length of conduit 14 and is closed at the end which is remote from the tunnel. Pipe 21 cooperates with the perforated conduit 14 to form an annular space 18. Pipe 22 is disposed coaxially within pipe 21 and is open at the end remote from the tunnel. Centralizer baffles 23 are installed at various intervals in the annular spaces between the pipe 21 and perforated conduit 14 and between the pipe 21 and pipe 22 to centralize pipe 22 within pipe 21 and to centralize pipe 21 within the perforated conduit 14. These centralizers are not continuous and they do not block fluid flow in the annular space. Pipes 21 and 22 cooperate with each other to form a continuous enclosed fluid flow path. Fluids may be introduced into either pipe 21 or pipe 22 and will exit through the other of these pipes. Supply of fluids to and from pipes 21 and 22 is accomplished by conduits 24 and 25 which are connected through suitable piping (not shown) to a source of heated fluid.

After the perforated conduit is suitably completed, a heated fluid is injected into the formation through conduit 14. Referring to the FIGURE, the heated fluid enters conduit 14 via pipe 27 and passes through passage 17 into the formation. The heating fluid may be any suitable fluid which is capable of heating bitumen in the formation to a sufficient temperature to cause the bitumen to gravitate downwardly into the conduit 14. For example, the fluid may be steam or may be a solvent vapor or may be a mixture of steam and air, or a mixture of steam and solvent such as carbon disulfide, hydrogen sulfide, naphtha, cracked naphtha, C_3, C_4, or C_5 hydrocarbons, toluene, xylene or benzene.

Following a suitable injection period, the heated fluid injection is discontinued and formation fluids including bitumen are permitted to drain into the annular space. Heated fluid is then circulated through pipes 21 and 22 to indirectly or conductively heat the fluids in annular space 18. Circulation of heated fluid through pipes 21 and 22 is continued with the fluid at a temperature sufficient to vaporize a portion of the drained fluids. The temperature of the circulated heated fluid will depend upon the boiling temperature in the annular space. This boiling temperature will typically range from about 250° F to about 750° F. The heated fluid in conduits 21 and 22 has a temperature higher than the fluids in annular space 18.

After a suitable indirect heating interval, bitumen is recovered from the formation by allowing it to drain through annular space 18 into conduit 26 from which it is pumped through suitable conduits to a conventional processing unit or is passed to storage.

The heated fluid circulated through heating assembly 20 may be any heat carrying gas or liquid which is capable of boiling fluids in annular space 18. Steam is suitable because it is relatively economical to produce and the temperature of the steam in the heater assembly will be substantially uniform throughout. In some cases other heat transfer agents such as diphenyl/diphenyl oxides mixtures may be preferable.

The diameter and length of the perforated conduit 14 will depend on the characteristics of the formation, conventional drilling criteria and economics of a given situation. However, the perforated conduits are typically from about 7 to 18 inches in diameter and from about 200 to 9000 feet in length.

To best exploit the effects of gravity in recovering the bitumen, the slotted or perforated conduit should be formed towards the bottom of the hydrocarbon-bearing formation. The production rate will usually be enchanced by locating the perforated conduit 10 to 50 feet above the bottom of the bitumen bearing zone. In addition, the borehole should be drilled slightly downward or upward depending on the well completion apparatus, to facilitate production of the bitumen to the earth's surface. With the configuration shown in the FIGURE, the borehole should slope upwards from the tunnel so as to allow gravity to move liquids towards the tunnel.

The composition of the liner and the concentric tubing string is a function of such factors as the type of injected fluid, flow rate, temperature, and pressure employed in a specific operation. The materials of construction may be the same or different, and may be selected from a wide variety of materials, including steel. The perforations in the casing would normally start several feet from the tunnel in order to reduce heating of the tunnel itself.

The steam injected into the formation, in the practice of this invention, can be generally high or low quality steam. Preferably, the steam is at least 50% quality and more preferably from about 70 to 100 percent. The steam may be mixed with noncondensable gases such as air or flue gas, or with solvents such as methane, ethane, propane, butane, pentane, naphtha, cracked naphthas, kerosene, carbon dioxide, carbon disulfide or hydrogen sulfide. A mixture of volatile solvents and steam will increase hydrocarbon drainage into the well. Volatile solvents injected into the formation with the steam will flow upwards into the formation to dilute the bitumen and thereby aid in reducing its viscosity. These solvents will tend to accumulate and reflux within the hot zone of the reservoir. Thus, the hot zone of the formation may contain relatively high concentrations of solvent with only a relatively small concentration of solvent injected with the steam. This is particularly important if reactive solvents such as hydrogen sulfide are to be employed.

The temperature of the fluid injected into the formation can be of any suitable temperature which is capable of mobilizing bitumen in the tar sand formation. In many instances, it will be desirable that the hot fluid have a temperature between about 250° F and about 600° F. Although operation with colder fluids is possible, this will tend to increase the requirements for indirect heat.

It should be understood any type of heating means which is capable of vaporizing fluids in the perforated conduit 14 can be used in the practice of this invention. A heating means such as an electrical heater can be associated with or located within the perforated conduit. The invention is, therefore, not limited to the heater assembly as described for the preferred embodiment.

The indirect heating of fluids in the annular space 14 facilitates drainage of bitumen into the well during the indirect heating stage. At least a portion of the water and hydrocarbons in the conduit are vaporized. The steam and hydrocarbon vapors help carry heat from the well into the formation and reduces viscosity of a larger amount of bitumen in the well.

The indirect heating stage of this invention also facilitates hydrocarbon drainage into the well by increasing the oil saturation in the reservoir pore spaces around the well. In conventional steam stimulation processes, the steam injection into the well tends to strip the oil on the reservoir pore spaces adjacent the well. These pore spaces then become water saturated and flow of oil into the well from the reservoir is restricted because of capillary pressure effects. During the indirect heating stage, however, the water in at least part of these pore spaces is vaporized and oil is permitted to occupy these spaces.

In another embodiment of this invention, after a heated fluid has been injected into the formation for a suitable time interval, formation fluids including bitumen may be produced from the formation by means of conduit 14. When production rates decrease to an uneconomical level, production is stopped and heated fluid is circulated through pipes 21 and 22 to indirectly heat the fluids in annular space 18. After a suitable indirect heating interval, bitumen is again produced from the formation by means of conduit 14.

In the broadest aspect of this invention, the conduit 14 can be disposed in any subterranean formation. The conduit can be extended, for example, from a vertical or deviated borehole which extends into the deposit, from a deposit which outcrops along a cliff, from a trench which extends from the earth's surface into the tar sands, or from a tunnel which is formed in the formation as illustrated in the FIGURE. Other means, of course, can be used to provide an exposed working surface.

Although the invention has been described in connection with the recovery of hydrocarbons from subterranean tar sand formations, it is also within the scope of this invention to employ the apparatus and method described herein to recover any liquids from any subterranean strata which can be stimulated by thermal energy. This invention can also be employed to recover hydrocarbons of much higher API gravity, e.g. 25° to 40° API.

FIELD EXAMPLE

This invention may be better understood by reference to the following example which is offered only as an illustrative embodiment of the invention and is not intended to be limited or restrictive thereof.

A tar sand formation is located at a depth of 1420 feet and has a thickness of 75 feet. The hydrocarbon viscosity is so high that it is almost immobile at the formation temperature. The formation temperature is 40° F and the formation pressure is 600 psig and the formation permeability is 2000 millidarcies.

A tunnel is formed in the tar sand formation along the bottom thereof by conventional means. A wellbore is drilled in an upward direction 1° from the horizontal into the formation for a distance of 2000 feet. Referring to FIG. 1, the well is completed with a steel liner which is slotted from a distance of 100 feet from the tunnel to the end. The liner slots 17 are about 0.03 inches in width. Dual concentric tubing string 21 and 22 are positioned in the liner and extend to approximately the entire length of the liner. Centralizers 23 centralize conduit 21 coaxially within liner 14 and centralize conduit 22 coaxially within conduit 21. Conduit 21 cooperates with perforated conduit 14 to form the annular space 18. Conduit 22 has a 3½ inch diameter and conduit 21 has a 5½ inch diameter and perforated conduit 14 has a 12 inch diameter. After completion of the perforated conduit, steam is introduced into the annular space 18 at a pressure of 1000 pounds per square inch for 10 hours. Steam injection is then discontinued and the well is shut in for 3 hours. During this soak period, the bitumen and steam condensate drain into the annular space 18. Subsequently, steam is circulated through conduit 22 into the annular space between conduits 21 and 22, and steam condensate is withdrawn through conduit 25. The steam is circulated at a pressure of 1000 psi for about 1 hour. Bitumen is then allowed to drain through annular space 18 through conduit 26 and then to storage or other production facilities. At the end of the production cycle, the steps of injecting steam in the formation, allowing the formation fluids to drain into the annular space, heating indirectly the formation fluids to force at least a portion of fluids into the formation, and recovering the fluids are repeated with each cycle length being increased until the reservoir being treated is depleted to the point where further production is no longer economically feasible.

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention, and it should be understood that this invention is not to be unduly limited to that set forth herein for illustrative purposes.

What I claim is:

1. A method for recovering hydrocarbons from a subterranean formation comprising

injecting a heated fluid into the formation by means of a perforated conduit which is disposed in a substantially horizontal manner within the formation to heat hydrocarbons within the formation to render the hydrocarbons more flowable;

terminating injection of the heated fluid into the formation to permit formation fluid including the heated formation hydrocarbons to flow into the perforated conduit;

heating the formation fluids within the perforated conduit to a temperature sufficient to vaporize at least a portion of said formation fluids to cause such vaporized fluids to pass from the perforated conduit and into the formation to further heat formation hydrocarbons to render the hydrocarbons more flowable; and

withdrawing heated formation fluids including heated formation hydrocarbons from the formation by means of the perforated conduit.

2. The method as defined in claim 1 wherein the heated fluid is steam.

3. A method as defined in claim 1 wherein the fluid injected into the formation is selected from the group consisting of steam, solvent vapors, a mixture of steam and air, or a mixture of steam and solvent.

4. The method as defined in claim 3 wherein the solvent is selected from the group consisting of carbon disulfide, hydrogen sulfide, naphtha, cracked naphtha, toluene, xylene or benzene.

5. The method as defined in claim 1 further comprising repeating the steps of injecting a heated fluid into the formation, terminating fluid injection to permit formation fluids to drain into said conduit and heating the formation fluids within in said conduit.

6. The method as defined in claim 1 wherein the formation fluids within the perforated conduit are heated by a heating means.

7. The method as defined in claim 6 wherein the heating means heats substantially the entire portion of the perforated conduit.

8. The method as defined in claim 1 further comprising before heating the formation fluids within the perforated conduit, withdrawing formation fluids including heated formation hydrocarbons from the formation by means of the perforated conduit.

9. A method for recovering viscous hydrocarbons from a subterranean formation containing viscous hydrocarbons comprising

positioning a perforated first conduit substantially horizontally into the formation;

disposing inside the perforated conduit dual concentric conduits comprising an inner conduit and a surrounding larger diameter intermediate conduit, said intermediate conduit and said perforated conduit cooperating to form an annular space, said inner conduit and said intermediate conduit cooperating to provide continuous enclosed fluid flow path through said inner and intermediate conduits;

injecting a heated fluid into the formation through said annular space and thereby reducing the viscosity of the formation hydrocarbons;

permitting fluids including formation hydrocarbons to drain into said annular space;

circulating a heated fluid through said inner and intermediate conduits to heat indirectly the drained fluids in said annular space; and

recovering the formation hydrocarbons from said annular space.

10. The method as defined in claim 9 wherein the heated fluid injected into the formation is steam.

11. A method as defined in claim 9 wherein the heated fluid injected into the formation is selected from the group consisting of steam, a mixture of steam and air, or a mixture of steam and solvent.

12. The method as defined in claim 11 wherein the solvent is selected from the group consisting of carbon disulfide, hydrogen sulfide, naphtha, C_3, C_4 or C_5 hydrocarbons, toluene, xylene or benzene.

13. In a method for recovering viscous petroleum including bitumen from a subterranean viscous petroleum containing formation including a tar sand deposit, said formation being penetrated by a perforated conduit which extends substantially horizontally therethrough, said perforated conduit being completed by dual concentric conduits comprising an inner conduit and a surrounding larger diameter intermediate conduit, said intermediate conduit and said perforated conduit cooperating to form an annular space, said inner conduit and said intermediate conduit cooperating to provide a continuous enclosed fluid flow path through said inner and intermediate conduits, said recovery method being of the type wherein a fluid is injected into the well for the purpose for increasing the mobility of petroleum contained in the formation, the improvement which comprises

injecting a heated fluid into the formation through said annular space and thereby reducing the viscosity of the formation hydrocarbons;

permitting fluids including formation hydrocarbons to drain into said annular space;

circulating a heated fluid through said inner and intermediate conduits to heat indirectly the drained fluids in said annular space; and

recovering the formation hydrocarbons from said annular space.

14. The method as defined in claim 13 when the heated fluid injected into the formation of steam.

15. A method as defined in claim 13 wherein the heated fluid circulated through said inner and said intermediate conduits is steam.

16. In a method for recovering viscous hydrocarbons from a subterranean formation comprising

positioning a perforated conduit substantially horizontally into said formation;

disposing in said conduit a heating means to heat fluids in said conduit;

injecting a fluid into the formation through said perforated conduit;

permitting fluids including the formation hydrocarbons to flow into said conduit;

heating said fluid in said conduit with said heating means to a temperature such that at least a portion of the drained fluid passes into said formation; and

recovering formation hydrocarbons from the formation through said conduit.

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Canada Patent [illegible]

Alberta OIL SANDS INFORMATION CENTER

006374

United States Patent [19]

Vandergrift

[11] **4,099,570**

[45] **Jul. 11, 1978**

[54] **OIL PRODUCTION PROCESSES AND APPARATUS**

[76] Inventor: **Donald Bruce Vandergrift, 264 Silverbrook Way N.W., Calgary Alberta, Canada**

[21] Appl. No.: **763,331**

[22] Filed: **Jan. 28, 1977**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**^{2} **E21B 43/24**

[52] **U.S. Cl.** **166/303**; 166/50; 166/62; 166/302

[58] **Field of Search** 166/263, 302, 303, 306, 166/272, 50, 57, 62

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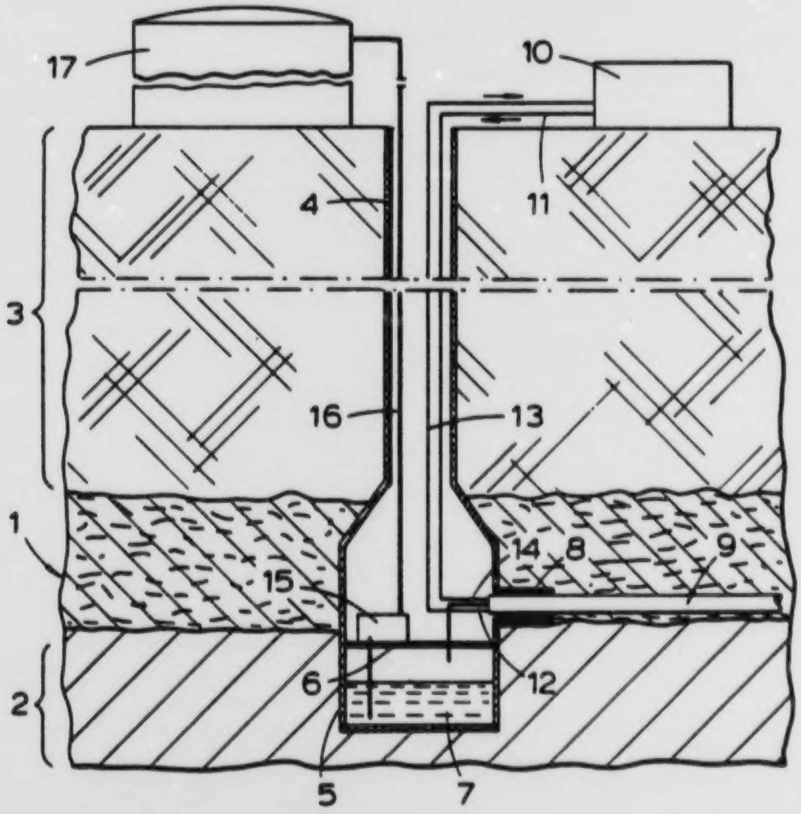
Primary Examiner—Stephen J. Novosad
Assistant Examiner—George A. Suchfield
Attorney, Agent, or Firm—Wofford, Felsman, Fails & Zobal

[57] **ABSTRACT**

A process and apparatus is described for use in the recovery of oil from natural oil-bearing formations such as tar sands by means of thermal energy causing the oil to gravity in the formation into an oil-receiving duct. Oil recovery in relation to installation and operating costs is improved by releasing heat into the formation at the site of the oil-receiving duct. For this purpose a composite heating and oil recovery string is used which is installed along the formation and comprises a tubular casing having oil-entry apertures and, internally of such casing, an oil-receiving duct and a passageway for the circulation of fluid heating medium.

9 Claims, 6 Drawing Figures



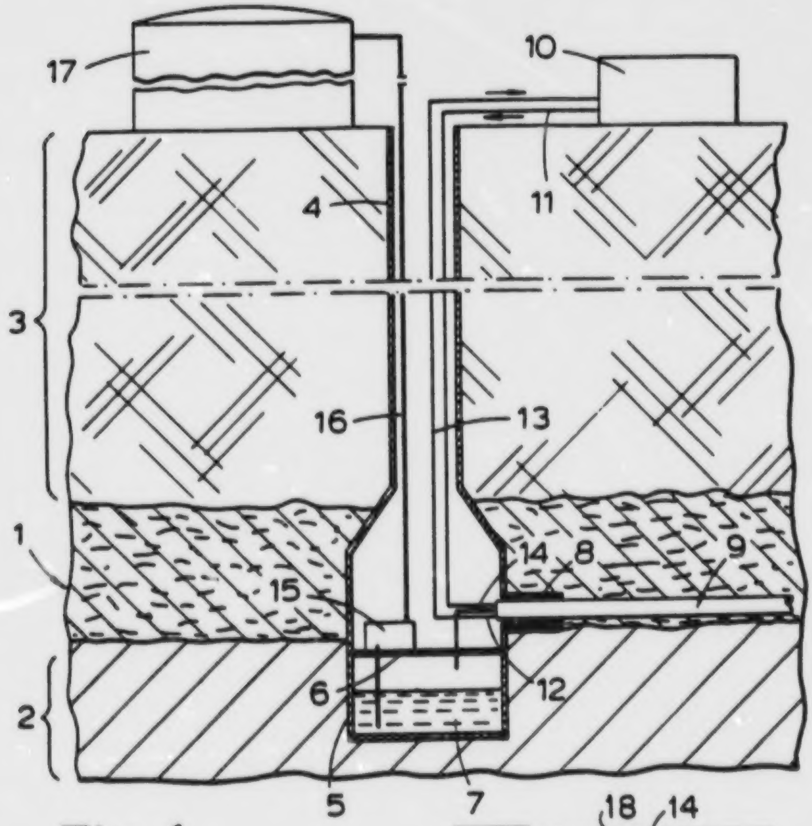

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Fig. 1

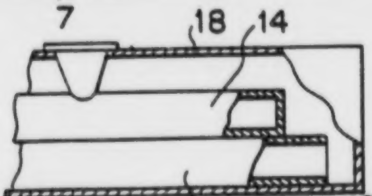

Fig. 2a

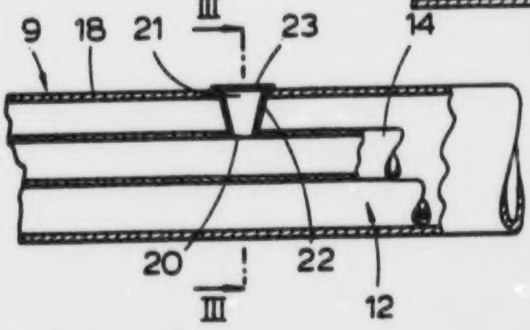
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Fig. 2

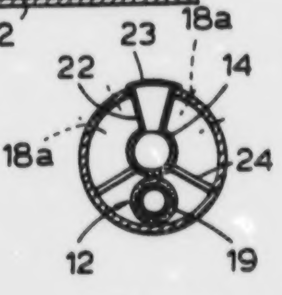
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Fig. 3

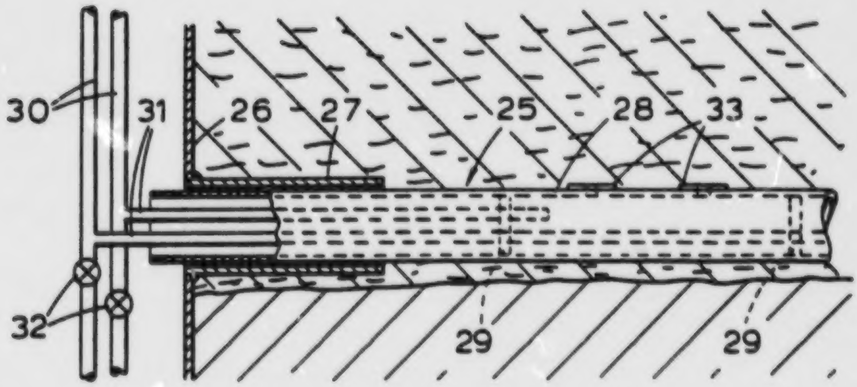
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Fig. 4

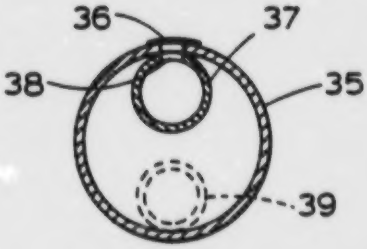
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Fig. 5

OIL PRODUCTION PROCESSES AND APPARATUS

This invention relates to an oil recovery string for use in the recovery of oil from natural oil-bearing formations. The invention also relates to oil recovery processes.

It is known to recover oil from natural oil-bearing formations with the aid of thermal energy supplied by a fluid heating medium. U.S. Pat. No. 3,386,508 describes a fluid-drive type recovery method wherein a well bore and a plurality of wells are drilled so that the wells intersect the well bore in the oil-bearing formation and a hot fluid is injected into the formation from the wells to cause viscous oil to flow into and accumulate in the well bore for recovery. The number and pattern of the drilling operations which this method requires make the production costs very high. The injection of fluid into the formation from the wells must over any given period of time be confined to a limited region along the wells so as to leave lengths of the wells free to receive lowered viscosity oil. Otherwise oil recovery is limited to that which flows directly into the central well bore.

Another type of recovery system employing thermal energy is described in U.S. Pat. No. 3,338,306 in which heating conduits extend along upper levels of the oil-bearing formation from a naturally exposed working surface of the formation or from a surface exposed by trenching, and heated fluid is circulated through these conduits to effect indirect heating of the oil in adjacent regions of the formation to a temperature such that the oil gravitates within the formation. As one method of recovering the heated oil the said United States Patent proposes the installation of a perforated pipe along the lower levels of the formation in a position where it will collect some of the oil as it reaches that level. In order to preserve a flow of oil through the perforations of the collecting pipe it is recommended that the pipe be installed in a drilled borehole of larger cross-section than the pipe, the reason being that the greater the space surrounding the pipe, the easier will be the collection of the gravitating oil. In order to maintain flow of oil into and along the collecting pipe this pipe is connected to pumps which pump the oil from the pipe to a surface recovery site. The preservation of a free space around the oil recovery pipe involves difficulties in practice when working unconsolidated formations such as tar sands. Therefore the oil recovery is liable to become seriously retarded in course of time. In addition it would be highly desirable to improve the economics of this type of recovery system by reducing installation costs and/or the energy consumption for a given rate of oil production.

It is an object of the invention to provide for the recovery of oil from oil-bearing formations, in particular unconsolidated tar sands, with improved efficiency and lower installation or operating costs.

A further object is to recover oil by means of an oil-recovery pipe with distribution of heat into the formation from the vicinity of such pipe.

A more particular object of the invention is an oil recovery string of composite form combining oil-recovery and heat distribution functions.

One important discovery underlying the invention is that when employing thermal energy to cause flow of oil within an oil-bearing formation into a collecting pipe, important advantages are achieved if heat is released into the formation at the site of the collecting pipe. In particular, favourable oil recovery rates can be more quickly achieved and long term recovery rates can be improved.

By providing an oil recovery string which serves both for oil collection and for heat distribution, the present invention enables these advantages to be realised and in addition makes an important contribution to reduction of costs by reducing the number of drilling or string driving operations required.

An oil recovery string in accordance with the present invention is characterised in that it comprises a tubular casing within which there is at least one internal passageway along which heated fluid medium (liquid or gas) for supplying thermal energy to a said formation can be passed, and at least one duct along which oil can flow along the string, said casing having oil entry apertures disposed at intervals therealong, which apertures are in communication with the interior of said duct.

The invention comprehends recovery strings which are formed to effect direct and/or indirect heating of the formation. In one type of string, it serves as a heat distributor from which heated fluid medium can be injected into the oil-bearing formation. In such apparatus, the string casing has fluid discharge orifices distributed therealong and houses interior fluid pipes leading to fluid discharge orifices in different portions of the length of the string.

In another type of string, which is the preferred type, the string serves as indirect heater, the fluid heating medium being isolated from the formation. In this type of apparatus, a fluid passageway within the string casing is defined at least in part by such casing and is open only at its ends so that it can form part of a closed circuit along which heated fluid medium can be circulated in heat exchange relationship with the casing. Such apparatus permits recovery of oil in its original form, i.e., without contamination by fluid heating medium.

Direct and indirect heating are not mutually exclusive. A string can have a fluid passageway through which heated fluid medium can be circulated, within the string, in heat exchange relationship with the string casing, and may have perforations via which a proportion of the fluid medium can escape into the formation.

The oil recovery string or strings may be formed in sections which are connected using jointing techniques known per se in the formation of conventional drilling strings.

The invention includes oil recovery installations incorporating one or more oil recovery strings as herein defined, as well as oil recovery processes wherein such installations are used. Such installations and processes can be applied to formations of any type of location but are likely to be particularly advantageous for producing oil from formations with an insufficient depth of overburden to permit oil to be driven from the formation by pressure. A very important example is tar sand reservoirs which are too deep or unsuitably located for surface mining techniques, but insufficiently deep for oil to be recovered by the known kinds of fluid injection technology wherein fluid is laterally injected into the formation from wellbores. There are known large area tar sand reservoirs with an overburden of from 150 to 500 feet which could be exploited by a process according to the invention. For working relatively shallow-lying formations it will generally be preferable to employ one or more strings according to the invention wherein the fluid heating medium is kept isolated from the formation, but if fluid injection from a string or strings located at the bottom of the formation is practised, the injection can be limited so as to avoid any tendency for the injection to break down the overburden.

Depending on the geology of the oil-bearing formation and other factors, the or each oil recovery string can extend downwardly into the oil-bearing formation from the surface or from a well or a trench or other excavated working site. In certain installations according to the invention the oil recovery string or strings is or are laid at an upward inclination from an oil collecting site where there is an oil sump so that flow of oil along the string or strings and into such sump occurs by or with the assistance of gravity.

Heat additional to that which derives from the heated fluid medium fed along the oil recovery string or strings can be supplied to the oil-bearing formation at other places in any desired manner, e.g. by fluid injection or by electrical heating means.

A method of oil recovery according to the invention can be carried out in conjunction with other oil recovery techniques if so desired. For example the flow of oil into the recovery string or strings can be assisted by fire flooding or by solution gas drive if in any given case that technique is compatible with environmental considerations.

Reference is now made to the accompanying drawings in which certain embodiments of the invention, selected by way of example, are illustrated. In these drawings:

FIG. 1 is a vertical section through part of an oil reservior production plant for producing oil by a process according to the invention;

FIG. 2 is a partly sectioned longitudinal elevation of part of an oil recovery string used in that process;

FIG. 2*a* shows the construction of that string at its distal end;

FIG. 3 is a transverse cross-section of the recovery string on line III—III in FIG. 2;

FIG. 4 is a detail of part of an installation for carrying out another process according to the invention;

FIG. 5 is a cross-section of another form of oil recovery string according to the invention.

An example of a process according to the invention will firstly be described with reference to FIG. 1. In this FIG., 1 is a tar or bituminous sand formation which overlies a subrock stratum 2 and is overlaid by an overburden 3 of between 150 and 500 feet in depth.

A vertical shaft 4 is driven from the surface to a level beneath the tar sand formation 1 and at the bottom of the shaft a cofferdam 5 is built. Within this cofferdam is a raised work floor 6 beneath which is an oil sump for receiving recovered oil 7. Secured to the wall of the cofferdam is a tubular guide 8 which may for example be about 10 feet in length. This guide serves to guide the direction which an oil recovery string 9 follows as the string, which is formed of successively conjoined sections, is advanced from the cofferdam. The guide is disposed so as to direct the recovery string along the bottom of the oil-bearing formation 1, supported by the subrock 2. The guide may for example have a radially inwardly projecting lug or tongue and the sections of the outer casing of the recovery string may have a receptive helical groove so that a twisting motion is imparted to the recovery string as it advances.

In suitable geological structures, rotary jet or nonrotary boring may be practiced for installing the recovery string, using a jet head fed with water via a tube passing along the interior of the casing of the recovery string and that tube may subsequently remain in place and may serve some other purpose, e.g., to convey cooled heating medium back to a heat generator. If the oil bearing formation is sufficiently consolidated, it can be bored by means of an auger.

In FIG. 1 only one oil recovery string is shown. There may and will normally be a plurality of such recovery strings radiating from the shaft so that oil can be simultaneously recovered from a number of different sectors around the shaft. When working a thick oil-bearing formation, one or more strings according to the invention may be provided at different levels of the formation. The jointed sections of the or each string may be of any length suitable for handling and transportation. The total installed length of each string may be as much as 500 feet or even 1000 feet or more, depending on circumstances pertaining to the geology of the formation and the available plant installation and oil receiving and storage facilities.

Steam is pumped from a steam generating plant 10 along a pipe 11 and into the casing of the recovery string 9. On reaching the distal end of the string (which end is closed), this heating medium, now relatively cool, flows back along a return tube 12 which extends along the interior of the casing, and then into an up pipe 13 leading back to the generator 10. Viscous crude in a zone of the oil-bearing formation 1 is heated by transfer from the heated string casing sufficiently to cause that oil to flow downwardly under gravity. A large proportion of this oil flows into the string and into an internal oil-receiving pipe 14. The recovery string 9 is slightly upwardly inclined to the horizontal from its source to its distal end. Consequently oil entering the pipe 14 flows therealong under gravity back to the shaft and discharges into the cofferdam sump. From this sump the oil 7 is pumped by a pump 15 along an oil delivery pipe 16 into an oil storage reservoir 17. Of course the flow of oil along the string could be achieved or assisted by a pump if required.

Due to the heating of the recovery string, oil recovery commences soon after circulation of the steam through the string is initiated. As a volume of the oil-bearing formation becomes heated by heat transfer from the string, gravitating oil tends to flow to the zone of highest temperature, i.e. to the site of the recovery string. Consequently the string receives oil from an area of the formation which is more extensive than the vertically projected area of the string. The oil recovery rate is therefore favourably high in relation to the heat energy consumed.

The construction of the recovery line 9 is shown in FIGS. 2, 2*a* and 3. It comprises a heat conducting casing 18 made of steel. Within this casing 18 there are the tube 12 which provides the return reach of the passageway along which the fluid heating medium is circulated within the string, and the oil-receiving pipe 14 which have already been referred to. The steam pumped into the string from the feeder pipe 11 flows along the interior of the casing, externally of the tube 12 and the pipe 14, and at the closed distal end of the string (shown in FIG. 2*a*) the steam enters the open end of the return tube 12 via which the steam flows back along the string to the up pipe 13. The fluid return tube 12 has an external thermally insulating cladding 19 to prevent significant heat absorption from the steam which is pumped into the string casing from the steam feeder pipe 11. The oil-receiving pipe 14, which is closed at its distal end (FIG. 2a), has oil-entry ports 20 at intervals therealong, at least in the top portion of this pipe wall. The string casing 18 has slightly larger oil-entry ports 21 opposite the ports 20 in the oil pipe 14. Funnel portions 22 are connected to the pipe 14 to conduct oil to its oil entry ports 20 and the wider ends of such funnel portions are secured to the casing at the locations of its oil-entry ports 21 so that oil from the oil-bearing formation flows via said funnel portions into the oil-receiving pipe 14. The oil-entry ports 21 in the casing 18 are fitted with screens 23 for retaining sand particles. These screens are shaped with convexly curved upper surfaces so that retained particles tend to be washed off the screen surfaces. In a well-consolidated formation, screens could be dispensed with. As appears from FIG. 3, the oil pipe 14 is supported by radial arms 24 secured to the casing 18. The fluid return tube 12 may be secured also to the casing, or may be secured to the oil pipe 14 so that the casing 18 and the internal tube and pipe form a unitary structure.

In a variant form of the oil recovery plant, a steam switch valve means is provided so that, at any time or times during production, some of the steam supply can be switched to the oil pipe 14 to cause steam to discharge into the oil-bearing formation through the screens 23. This is useful for clearing the screens and boost-heating the formation.

The jointed sections of the oil recovery string may for example have a length of about 30 feet. The diameters of the casing 18, the internal fluid return tube and the oil-pipe will be selected depending on circumstances. As an example the casing may have a diameter of from 9 inches to 14 inches. The diameters of the fluid return tube and oil pipe must be sufficient for the required throughput capacity of cooled heating medium and recovered oil but must leave sufficient free space within the casing for the passage of steam at a volume rate appropriate to the required heat output from the recovery line.

In a modification of the process described with reference to FIGS. 1 to 3, the casing 18 is provided with perforations such as perforation 18a shown in dotted line in FIG. 3 to allow a proportion of the steam or other fluid heating medium to escape into the oil bearing formation.

As an example of a jointing system for the successive recovery string sections, the casing sections can be joined by welding and the lengths of the oil pipe and fluid return tube belonging to the different string sections can be formed for spigot and socket type connection, the spigot-forming end of one length having fitted sealing or packing rings which seal against the inner surfaces of the socket-forming end of the neighbouring length. This type of joint is well known to those conversant with oil recovery technology.

As an indication of the efficacy of plant as represented in FIGS. 1 to 3, if steam is circulated through the or each oil-recovery string at a temperature and flow rate corresponding to a heat input of between 500 and 1000 BTU/hr per square foot of the string casing surface then, depending on the composition of the oil reservoir, the temperature of the oil-bearing sand at regions from 6 to 10 feet from the string can be raised sufficiently to induce oil flow from such regions within a period of one year. However the energy input can be substantially outside this range. The optimum values of the various parameters such as heat input rate, number

of strings etc. can be determined from pilot projects and calculations for a given location.

It is not essential to provide a working shaft such as 4 in FIG. 1. One or more small diameter wells may be drilled which communicate with the recovery string(s) and which is or are associated with means whereby the circulation of steam or other heating fluid through such string(s) can take place via such well(s). Oil can be pumped to the surface via one or more such wells or from a different location. For example a pattern of vertical wells, mutually spaced e.g. by 40 to 60 feet from each other could be linked by a system of recovery strings according to the invention each extending from one well to another.

FIG. 4 shows part of another oil-recovery string according to the invention. This recovery line 25, extends along the bottom or lower region of an oil-bearing formation from a shaft 26 fitted with a line guide 27 similar to guide 8 in FIG. 1. In the FIG. 4 embodiment the recovery string comprises a tubular casing 28 which is internally divided by partitions 29 into successive compartments. Vertical steam pipes 30 extend from a steam generator at the surface down to an oil sump at the bottom of the shaft and branch pipes such as 31 extend from these vertical pipes to the different interior compartments of the casing 28. The vertical steam pipes are fitted with valves such as 32 for controlling steam flow. In each portion of its length corresponding with one of the said interior compartments the casing 28 has at least one peripheral port such as 33 opening upwardly into the oil-bearing formation. The said ports are if necessary fitted with sand screens.

Steam under pressure is injected via the branch pipes into the internal compartments of the casing 28 so as to discharge upwardly from these compartments through the sand screens. The pumping of steam from each compartment occurs intermittently. For example, steam may be pumped from any given compartment or any given group of compartments for a period of one or more days or even a week or more, to be followed by pumping of steam from another compartment or group of compartments. When steam delivery to certain compartments is terminated, the corresponding valves 32 are opened. Oil which has been heated during the steam delivery from such compartments can now drain into such compartments via the screened ports 33. Once such compartments contain liquid up to a certain level, oil entering the compartments commences to discharge via the associated pipes 31 into the connected vertical pipes 30 along which the oil drains to the sump. To permit such discharge of oil, the conduit 28 is laid at a slight upward inclination from the shaft. Alternatively oil entering the compartments of the conduit can be drawn off by pumps.

By virtue of the division of the string casing into compartments, which compartments or groups of which compartments are associated with independent supply pipes for heated fluid a favourable heat distribution along the string can be ensured. If steam is merely fed into a perforated pipe the steam tends to escape via the shortest route and the heat distribution in the formation would be poor.

FIG. 5 shows a further form of oil recovery string. The string sections each comprise a casing 35 having oil-entry ports 36. Within the casing there is an oil-receiving pipe 37 having oil-entry ports 38 and the casing 35 and pipe 37 are secured together, e.g. by welding, so that the ports 36 and 38 are in sealed communication. Steam or other heated fluid medium can be supplied along the string between the oil-receiving pipe 37 and the casing so as to heat the casing and the oil-receiving pipe. The string can for example be installed between two shafts with flow of the heating medium from one shaft to the other. If required a tube 39 may be provided within the casing so that return flow of heating medium can take place within the string, through this tube.

An oil recovery string according to my invention could be used in processes other than those hereinbefore described. For example, such a string, preferably fitted with screening means for retaining solid particles above a certain size, can be used in oil recovery by installing the string depthwise of the oil-bearing formation, e.g. as part of a drilling pipe or string driven down to the formation from the surface. It may be possible to dispense with a shaft. A plurality of such strings could be driven at a given production point. Depending on the form of the string, heating may take place by injection of hot fluid medium from the string and/or by internal circulation of steam or other hot fluid medium within the string.

Having thus described the invention it will be understood that such description has been given by way of illustration and not by way of limitation. Numerous modifications, additions and subtractions may be made to the illustrated embodiments without departing from the spirit or scope of the invention.

I claim:

1. An oil recovery string for use in recovering oil from a natural oil-bearing formation with the aid of thermal energy supplied by a fluid-heating medium, said string comprising a tubular heat-conducting casing having oil entry apertures disposed at intervals therealong, an oil-receiving pipe located within said casing and having peripheral openings in sealed communication with said oil-receiving apertures in the casing, and wherein between said casing and said oil-receiving pipe there is a passageway along which heated fluid medium can be circulated in heat-exchange relationship with the casing.

2. An oil recovery string according to claim 1, wherein the string is formed so that the whole or substantially the whole of the interior surface of said casing is exposed to heated fluid when this is circulated along said passageway.

3. An oil recovery string according to claim 1, wherein said oil-receiving pipe is disposed so that its axis is substantially centrally located within the cross-section of said casing, wherein there is a tube extending along said string, between said oil-receiving pipe and the casing, and wherein the interior of said tube and the free space which is external to said tube and is between the oil-receiving pipe and the casing constitute reaches of a said passageway along which heated fluid medium can be circulated within the string.

4. A process for recovery of oil from a natural oil-bearing formation utilising thermal energy supplied by a fluid heating meadium to cause or accelerate flow of oil from the formation into an oil recovery duct, with the improvement that in a direction along the formation there is installed at least one composite heating and oil recovery string having a heat conducting casing within which there is at least one passageway for conducting fluid heating medium along the string in heat exchange relationship with such casing, and within which casing there is also at least one duct for conducting oil along the string, the said casing having peripheral oil entry apertures at intervals therealong (via) which apertures are in sealed communication with (the) said oil-receiving duct located within said casing, (is in communication with the formation,) and fluid heating medium is (circulated) forced along said heating passageway to heat a volume of the oil-bearing formation by heat transfer from the string so that oil is caused to gravitate from the formation into said oil-receiving duct via said oil entry apertures.

5. A process according to claim 4, wherein said string extends along the formation at an inclination so that oil entering said oil-receiving duct flows therealong under gravity.

6. A process according to claim 4, wherein within said casing there is also a return tube for the fluid heating medium and the fluid heating medium is forced along said passageway in contact with said casing, from one end of said string to the other end thereof, at which other end said fluid heating medium enters said return tube and then flows along that tube back to said one end of the string.

7. A process according to claim 4, wherein the opposed ends of said casing are connected into a closed circuit along which the fluid heating medium is circulated.

8. A process for recovery of oil from a natural oil-bearing formation utilizing thermal energy supplied by a fluid heating medium to cause or accelerate flow of oil from the formation into an oil recovery duct, with the improvement that in a direction along the formation there is installed at least one composite heating and oil recovery string comprising a tubular casing having ports at intervals therealong via which the interior of the casing is in communication with the formation, and comprising a plurality of fluid conducting pipes which extend along the interior of said casing and are in communication with ports in different portions of the length of the string, and at intervals of time fluid heating medium is forced along said pipes and into said formation via said ports to heat a volume of the oil-bearing formation so that oil is caused to gravitate from the formation into said oil-receiving duct via said ports.

9. An oil recovery string for use in recovering oil from a natural oil-bearing formation with the aid of thermal energy supplied by a fluid heating medium, said string comprising a tubular casing adapted to be laid in a direction along an oil-bearing formation, said casing having ports at intervals therealong via which oil gravitating from regions of the formation above the string can enter said casing, and having partitioning means subdividing the interior of the casing into different compartments distributed along the casing, and a plurality of fluid conducting pipes which extend along the interior of said casing and have fluid discharge ends thereof disposed in different said compartments to permit heating fluid to be intermittently discharged from ports in different portions of the length of the casing, for heating oil in said regions of the formation, by forcing such medium intermittently through said pipes.

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Alberta OIL SANDS INFORMATION CENTER 006370

United States Patent [19]

Rabbitts

[11] 4,101,172

[45] Jul. 18, 1978

[54] IN-SITU METHODS OF EXTRACTING BITUMEN VALUES FROM OIL-SAND DEPOSITS

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[30] **Foreign Application Priority Data**

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[51] Int. Cl.^{2} E21B 43/25; E21C 41/10

[52] U.S. Cl. 299/2; 166/271; 166/272

[58] Field of Search 299/2

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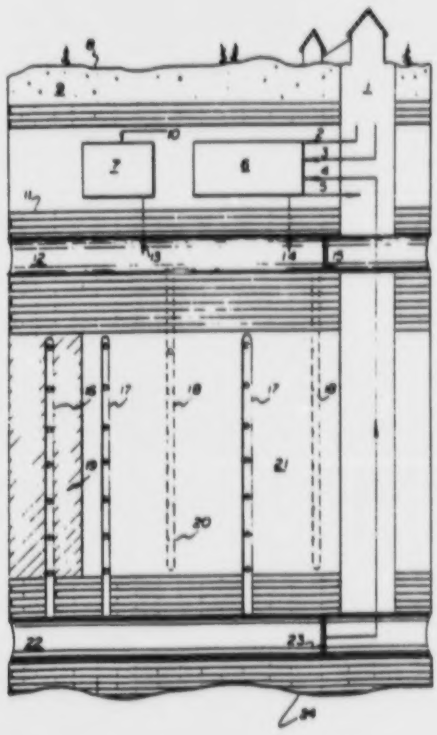
Primary Examiner—Ernest R. Purser
Attorney, Agent, or Firm—Murray and Whisenhunt

[57] ABSTRACT

The present invention provides a method of in situ extraction of bitumen from an oil-sands body which method comprises sinking an access shaft through the oil-sands body, driving an access drift in the rock strata underlying the oil-sands body, delineating a rectangular block of oil-sands in said body by drilling and blasting the oil-sands body to provide substantially vertical planes of fractured oil-sands on all four sides of an enclosed mining room capable of retaining liquids and gases under pressure and comprising solid pillar walls, providing generally upwardly extending bores in said block of oil sands from the access drift in the said body, providing perforated pipes in those portions of the bores in said block, the perforations of said pipes being dimensioned to prevent sand particles from said block passing therethrough, increasing the permeability of the block of oil sands within said room by fracturing said block, flooding the mining room with a hot fluid at a temperature and for a residence time sufficient to raise the temperature of the block by an amount to cause the bitumen to become flowable with said fluid and removing the fluid-bitumen mixture so formed from said block, the passage of said fluid through said bed being via said perforated pipes and separating said bitumen from said fluid.

40 Claims, 5 Drawing Figures



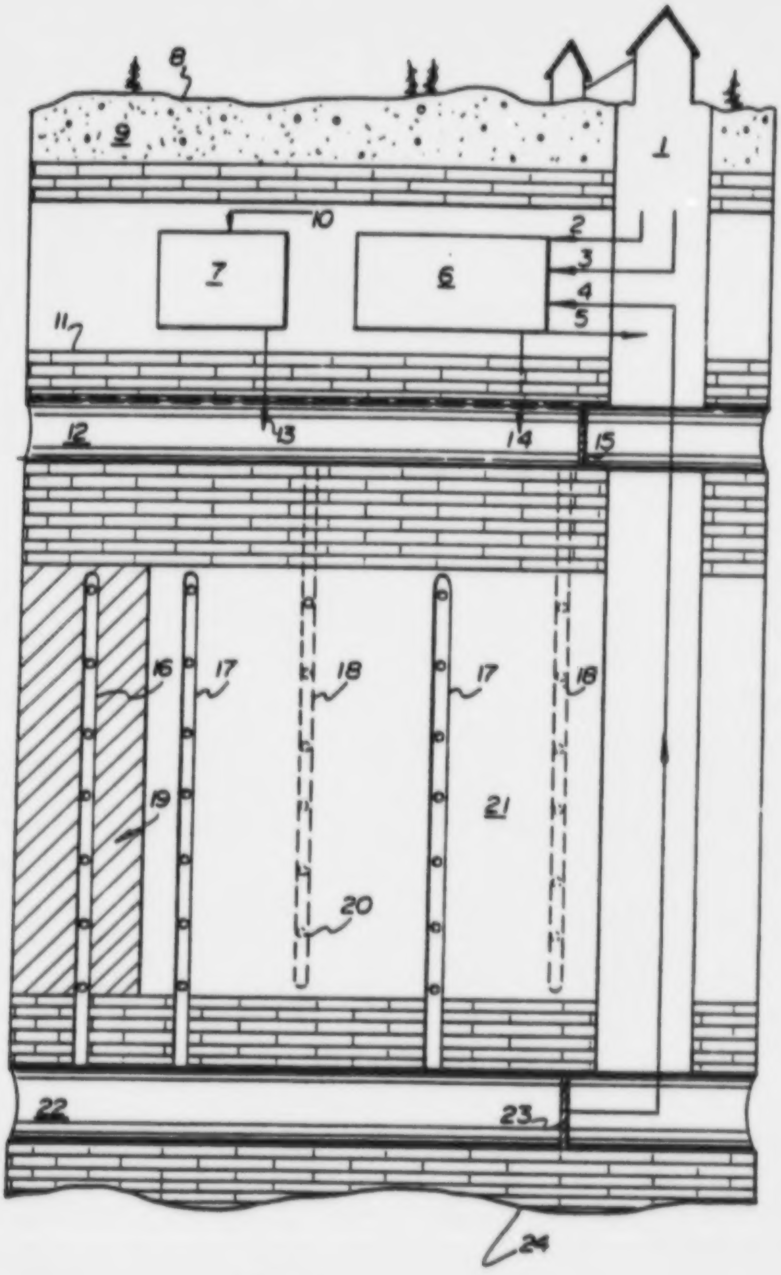

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FIG. 1

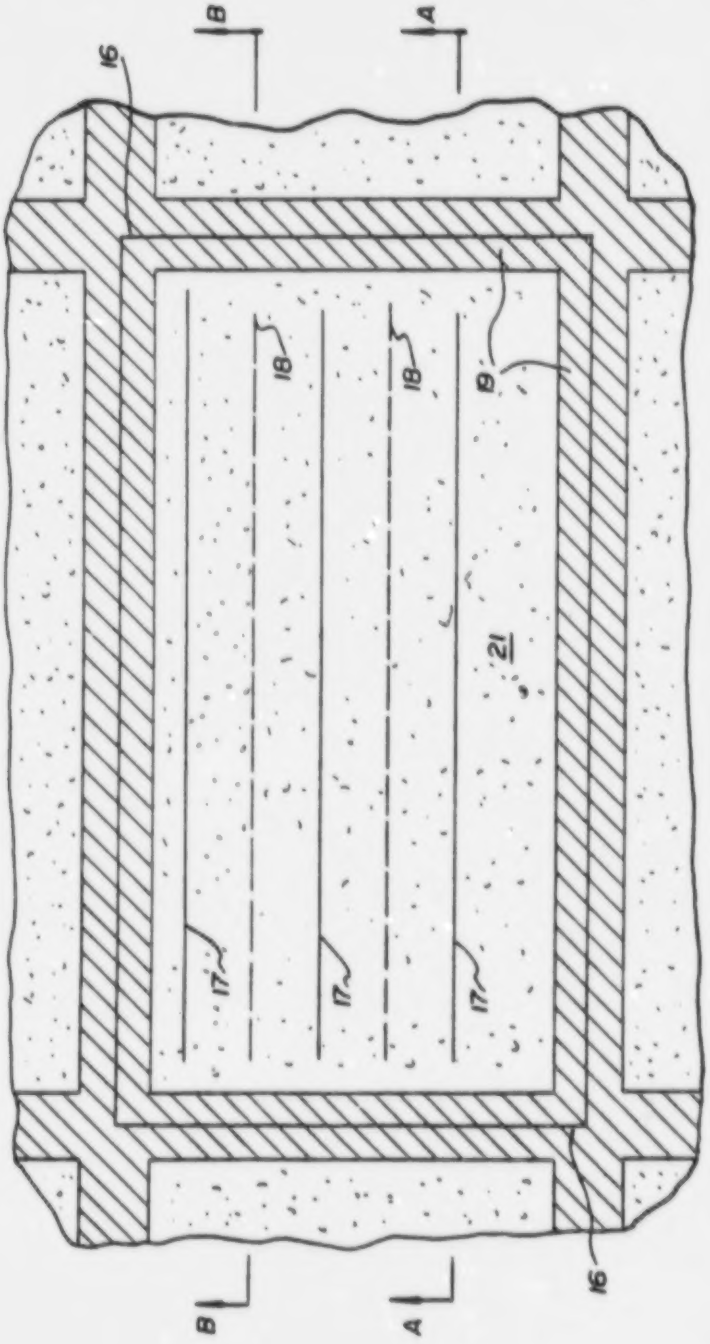
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FIG. 2

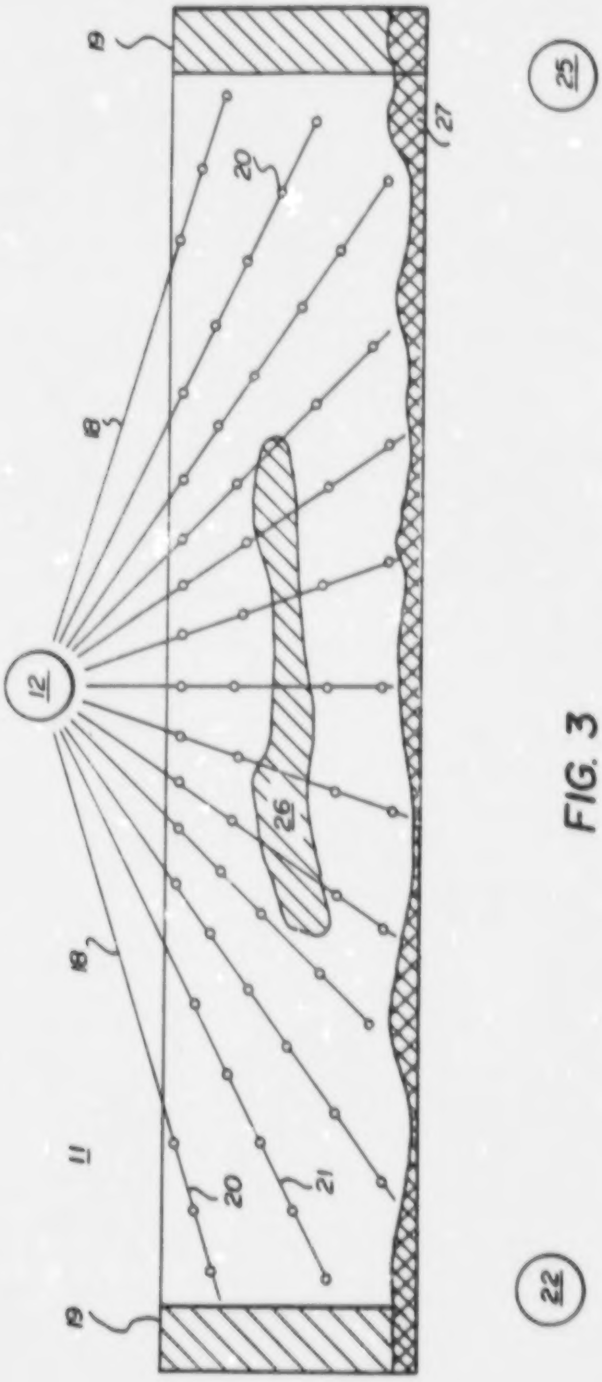
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FIG. 3

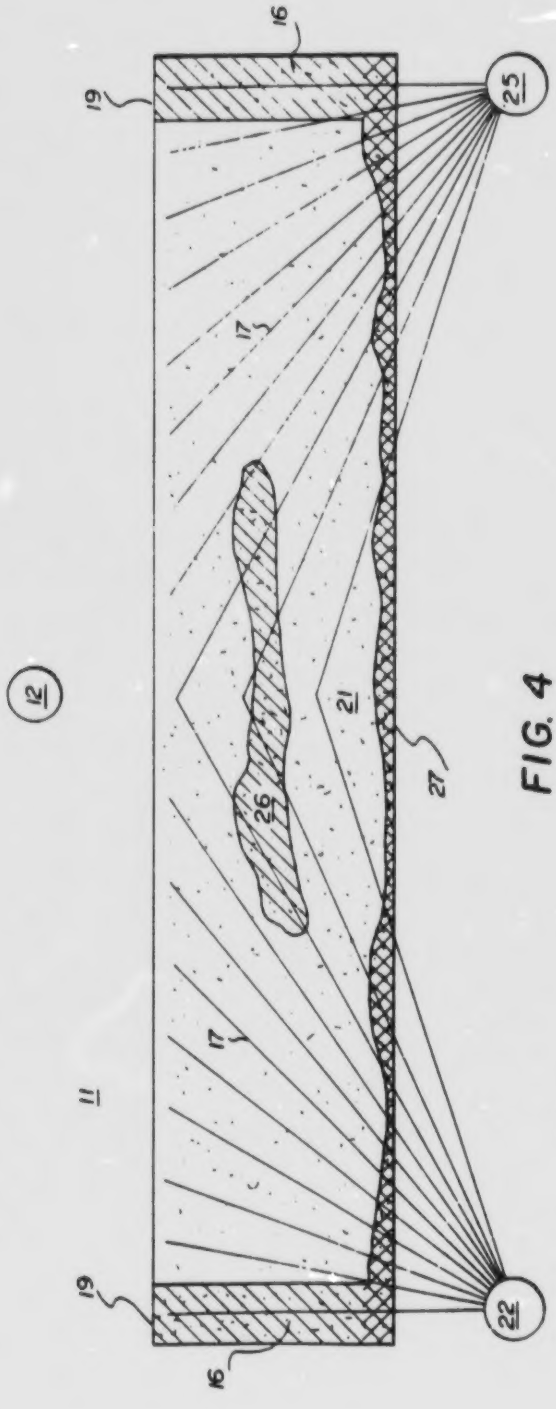
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FIG. 4

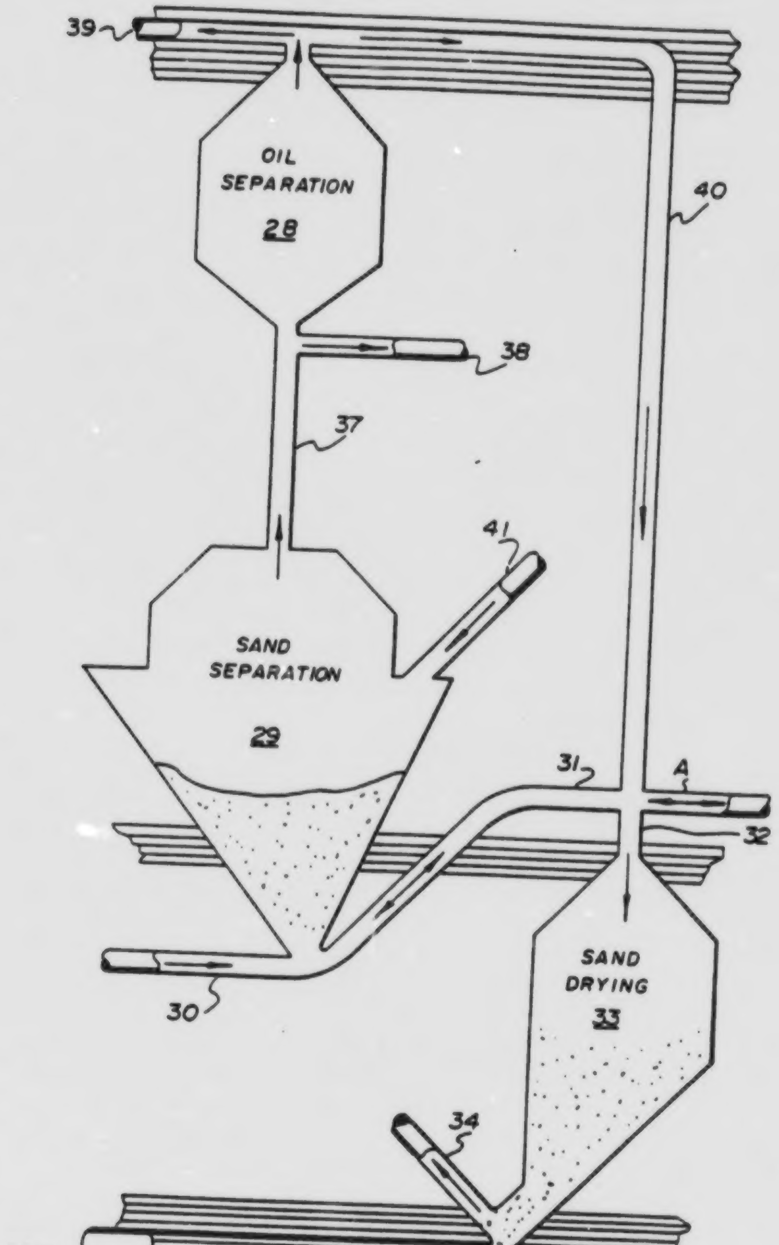
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FIG. 5

IN-SITU METHODS OF EXTRACTING BITUMEN VALUES FROM OIL-SAND DEPOSITS

The present invention relates to the recovery of hydrocarbons from oil-sands. In particular, the present invention relates to a method of in situ recovery of hydrocarbons from oil-sands deposits at any depth of burial without disturbing the overburden and without contamination of surface water. The method of the present invention is particularly suitable for the recovery of bitumen from low grade oil-sands employing a low level of mechanical equipment, having low maintenance and operating costs and utilizing a low level of labour. The method of the present invention takes place underground and thus avoids climatic problems associated with the conventional commercial methods of obtaining hydrocarbons from oil-sands deposits and allows uniform year round operating conditions.

Deposits of bituminous sand are found in various localities throughout the world. The term "bituminous sand" as used herein includes those materials commonly referred to as oil-sand and tar-sand and the like. Large deposits of these bituminous sands are located in Northern Alberta, Canada where the four major deposits cover an area of 19,000 sq. miles and contain about 600 billion barrels of reserves in place. The largest deposit is the Athabasca deposit which contains over two-thirds of all Alberta's bituminous sand reserves.

Several basic extraction methods have been known for years for the separation of bitumen from the sands and are now operated on a commercial scale. They include the so-called "cold water" method and the "hot water" method. Both of these methods involve open pit mining methods utilizing bucket wheel excavators or draglines. The initial step in these processes is the removal of overburden preceded by clearing of the ground surface. The surface of the oil sands mining area is often characterized by swamps and muskeg with poor drainage. Initial removal of tree and plant cover helps the surface to dry naturally. After removal of trees and roots etc. the overburden can be removed using conventional earth moving equipment. The overburden, which is defined as the thickness of the sediment above a desired grade of oil sand will depend upon the cutoff value chosen and will include a varying thickness of poorly saturated silty oil sands commonly found on top of the oil sands formation. In addition to the lower grade oil sands, the overburden may also include marine sandstones and shales plus glacial till, swamps and muskeg or some combination of these groups. Thus the depth of burial from the surface to the top of commercial oil impregnated strata can vary from 0 to 2000 feet. The depth of overburden and grade of oil sands are the principal determining factors which decide the economic feasibility of open pit mining methods. At the present time less than 10% of Alberta's oil sand reserves can be recovered by open pit mining methods due to excessive depth of the overburden.

One problem associated with oil sands open pit mining operations is extreme conditions of weather and climate which in Northern Alberta includes extreme cold in wintertime. Most of the oil sands deposits there are covered with an overburden and when the overburden is removed and the oil sands laid bare and exposed to the cold, frost penetration can be evident down to a depth of 10 feet below the exposed oil sand surfaces. In the summertime, the oil sands may be soft and heavy machinery can sink in to the exposed sand beds. The degree of ground softness however, depends not only on the summer temperatures but also on the bitumen content, the particle size of the sand, the amount of moisture and the gas concentration in the oil sand. Thus, under normal summer conditions, the viscous fluid film between the sand grains binds the mass together like a fine grained asphalt road mix and the oil sand on the mining faces is minable without prior preparation. In the wintertime, a mining face which has not been disturbed is similar to concrete but tougher and will not shatter in the cold. The bitumen matrix between the sand grains is merely more viscous. Under these operating conditions, excavating the face is virtually impossible without first loosening with explosives. Mechanical equipment is subject to violent abuse and maintenance efficiency in subzero weather is very low. Once the frozen surface is penetrated, the sand excavated is about 40° F. In excavating the 40° F material, the water envelope around the sand particles is ruptured. A considerable amount of water vapour is released into the atmosphere and visibility drops. The water tends to freeze and frozen masses of oil sands adhere to the digging equipment, freeze to the conveyors, build up in the transfer points and cause general distress. Occasionally large blocks of frozen sand may peel out along the planes of weakness and endanger the machinery working below. Another problem caused by frozen lumps is the additional damage and wear to mechanical equipment such as excavators, conveyors, chutes, feeders, and conditioning drum baffles as well as the additional steam requirements necessary to heat this frozen material up to the required 170° F range for the hot water processing.

Another problem encountered during winter operation of open pit mining has been the difficulty in breaking down large frozen lumps of oil-sands during the mulling operation in the hot water process. At low temperatures, the oil-sands from the mining area are rock hard. Significant amounts of these sands are not reduced and broken down during the mulling period, but pass through the conditioning drum as oversize which is removed by screening and the losses of these oversize rejections, still containing recoverable bitumen, are significantly higher in the winter months than in the summertime. In large plants, oversize rejections can range from 10,000 to 15,000 tons daily.

Another problem associated with the hot water method is the difficulty in re-using all the plant water. The major portion of the water contained in any bitumen and water emulsion must be separated before the oil is delivered to the refinery. The water from this separation step must eventually be stored, disposed of or recycled back into the process. Because this water contains bitumen emulsions, finely dispersed clay with poor settling characteristics and other contaminants, water pollution considerations prohibit discarding the waters into rivers, lakes or other natural bodies of water. Typical pond water assays from existing hot water processes contain up to 12% suspended solids, between 80 and 100% of which is fine clay of a size small than 2 microns. The pond water also contains about 0.1 to 0.5 weight percent bitumen. Because of the particular composition of the pond water, it cannot be discarded or to any great extent recycled back to the hot water process.

Most of the oil in the Athabasca oil sands is contained in fluviatile sand and fine grained well sorted sands. The basal member oil sands are composed of poorly sorted coarse grain sands, sand stones, and pebble conglomerates. The middle member oil sands are fine grained well sorted quartz sands, which are the richest oil sands and may be present in thickness of up to 220 feet. These sands can contain up to b 14% by weight or 28% by volume and then they are fully saturated with oil. The upper member of the oil sands is composed of thinly bedded horizontal sands and silts. These are often poorly impregnated with bitumen and commonly classed as overburden as mentioned heretofore. However, the upper member oil sands vary widely in sorting and grain size, bedding, and oil content and may contain an appreciable amount of oil in some areas. Thus, the stratification or bedding of the bituminous sands over much of its extent has been shown to be irregular and under normal circumstances saturated bituminous sand beds may be spotty, erratic and discontinuous. The oil sand deposits have much debris scattered throughout usually in the form of wood fragments, pebbles, iron conglomerates, siltstone lenses, shell beds, barren shales and very hard rounded stones of up to 6 inches in diameter composed of sand and clay cemented by pyrite. Thus, within the deposit are substantial lenses of low grade oil-sands containing 4 to 6% bitumen or less by weight, which are currently considered uneconomical to recover, plus other numerous zones and inclusions that are devoid of oil which include large beds of water sands, gas sands, barren shales, hard siliceous sandstones, clay beds, thin coal seams and siderite cemented lenses. It will be readily realized that in the open pit mining procedures now in commercial operation in conjunction with the hot and cold water methods of extraction, the oil sands together with all these inclusion are mined and passed to the extraction plant. This condition is undesirable to an extent that on frequent occasions due to the proportion of the inclusions in the particular oil sands being mined, the daily output of the extraction plant can be very irregular with its operation substantially curtailed.

Further, the natural state of the water-wet sand grains of the oil sands is a very fragile condition and if disturbed can cause irreversible conditions detrimental to the recovery of bitumen values. Mechanical handling is required in the conventional open pit mining technique and the hot and cold water extraction processes. The digging, conveying, mulling and pumping steps combined with the evaporation of water films from the sand grain surfaces during the exposure to air can often lead to a condition of oil-wet sand grains which decreases recovery and increases both oil and waste water contamination.

It thus will be readily realized that the conventional commercially operated extraction techniques for removing bitumen from oil sands are subject to many disadvantages and further are not utilizable for a substantial amount of the oil sands present for example in the Athabasca oil sand formation due to the depth of the sands, i.e., the extent of the overburden.

Deeply buried oil sands may of course be mined by underground mining techniques. However, such mined oil sands would be treated according to the conventional hot water and cold water methods for the extraction of bitumen therefrom and thus would be subject to the aforesaid disadvantages inherent in such techniques. Further, in such an underground mining method provision must be made for the adequate safety of both men and equipment and it is extremely difficult to maintain a conventional mechanical mining operation in which the mechanical equipment and the men are working directly within the ore body itself. The problems involved in scaling and supporting a roof and side walls against collapse or cave-ins in the unconsolidated oil sands containing such a multiplicity of vertical, horizontal and inclined bedding planes make such a procedure virtually impossible.

Proposals have therefore been made for extracting the bitumen from the oil sands by an in situ technique in which the oil sands are not removed from their location in the ground. However, such processes have heretofore not been found to be commercially useful.

The present invention provides a method of in situ extraction of bitumen from an oil sands body which is not subject to the disadvantages of the conventional and commercially operated cold and hot water extraction processes involving open mining of the oil sands body. This invention is operable under constant year around temperature conditions, provides for the economic recovery of hydrocarbons from the oil sands deposits, extracts bitumen values from the oil sands deposits at any depth of burial without disturbing the overburden, eliminates essentially all the mechanical problems caused by severe climatic conditions, maintains the natural water-wet condition of the oil sands until the bitumen values have been extracted, eliminates contact of the oil sands with unsaturated air and therefore avoids any evaporation of the water film on the oil sands, eliminates essentially all mechanical handling until the bitumen values have been extracted, is capable of selectively mining the irregularly bedded oil sands, provides for the separation of the oil-mineral-water fractions underground delivering separated oil to the surface as a hot liquid, provides for underground disposal of all silty and clayey waste products and provides for the clarification and re-use of process water.

According to the present invention therefore there is provided a method of in situ extraction of bitumen from an oil sands body which method comprises sinking an access shaft through the oil sands body, driving an access drift into the rock strata underlying the oil sands body, delineating a rectangular block of oil sands in said body by drilling and blasting the oil sands body to provide substantially vertical planes of fractured oil sands on all four sides of the enclosed mining room capable of retaining liquids and gases under pressure and comprising solid pillar walls, providing generally upwardly extending bores in the block of oil sands from the access drift in said body, providing perforated pipes in those portions of the bores in said block, the perforations of said pipes being dimensioned to prevent sand particles from said block passing therethrough, increasing the permeability of the block of oil sands within said room by fracturing said block, flooding the mining room with a hot fluid at a temperature for a residence time sufficient to raise the temperature of the block by an amount to cause the bitumen to become flowable with said fluid and removing the fluid bitumen mixture so formed from said block, the passage of fluid through said bed being via said perforated pipes and separating the bitumen from said fluid.

In the method of the present invention an access shaft is driven through the oil sands body and an access drift is driven into the rock strata underlying the oil sands body from which access drift a hot fluid and/or fluid bitumen mixture can be fed to and/or removed from the oil sands body. Thus, generally upwardly extending bores are drilled from the access drift into said body, the bores having disposed therein perforated pipes at least in those of the bores in the body and possibly also in those parts of the bores in the rock strata. However, the bore in the rock strata itself may act as suitable conduit for the passage of the fluids or fluid-bitumen mixture. The perforations in the pipes of course are dimensioned to prevent sand particles from the body passing therethrough. In the method of the present invention therefore, the hot fluid is introduced into the oil sands body in any suitable manner and desirably under pressure thereby to flood said body and remain therein for a residence time sufficient to raise the temperature of the body by an amount to cause the bitumen to become flowable with the fluid and the fluid-bitumen mixture so formed is subsequently removed from the body. In a particularly desirable embodiment of the present invention, the mixture of fluid and bitumen is removed from the body through the perforated pipes. The perforated pipes thus desirably constitute inter alia drainage pipes.

In order to prevent hot fluid introduced into said body for the purpose of removing bitumen therefrom from passing along said body inter alia through cracks and fissures thereby being lost to the process and also to allow for a desirable maintenance of high pressure within said body in the process of the present invention for the passage of liquid through said body, the body is delineated into a rectangular block of oil sands by drilling and blasting the oil sands body thereby to provide substantially vertical planes of fractured oil sands on all four sides of an enclosed mining room which mining room is capable of retaining liquids and gases under pressure and comprises solid pillar walls. Thus the present invention involves a room-and-pillar method of mining, the pillars acting as barriers between adjoining rooms. The overlying shale and underlying limestone strata serve together with the pillars to enclose a room containing a rectangular block of oil sands ready for fracturing suitably by blasting and for extraction with the hot fluid. It is also desirable, in order to allow for natural fractures and channels throughout the oil sands body including that portion which forms the pillar walls which permit leakage away from the mining room, of substantial amounts of valuable hot fluid, to line the inside of the pillar walls surrounding the mining room with a fence of suitably disposed drainage pipes which intercept any hot fluid that may tend to escape from the mining room through the walls. Further, by suitable blasting techniques oil sands areas surrounding this retaining fence of drainage pipes can be artificially fractured to collapse and destroy any natural fissures or channels in the pillar walls and provide a highly permeable zone of fractured oil sand around the drainage pipes through which any escaping fluid may find its way to the fence drainage system. By maintaining a lower pressure in the fence drainage system than in the mining room, a suitable barrier for escaping fluids is provided. A horizontal tunnel system directly beneath the drainage fence in the rock strata suitably forms a rectangle underneath the outer perimeter of the room and the tunnel system serves as an initial storage reservoir for the hot fluid, which hot fluid suitably after heat exchange to raise its temperature once more may be recirculated to the mining room suitably together with hot fluid and bitumen mixture withdrawn as desired from the mining room. To maintain a differential pressure between the fence drainage system and the mining room the former suitably discharges into a tunnel reservoir separate from that of the mining room. Suitably the fluid from the mining room discharges into tunnel reservoirs beneath the pillars on one pair of opposite sides of the mining room and the fence drainage system discharges hot fluid into tunnel reservoirs beneath pillars on the other pair of opposite sides of the mining room. For such a system the drainage fence is formed from vertically disposed drainage pipes on the pillars said other pair of opposite sides of the drainage room and the pillars on said one pair of opposite sides of the drainage room have suitably inclined bores. The tunnels may be on different levels and their functions may be reversed for subsequently removing bitumen from the pillars.

The object of the process of the present invention for the recovery of the bitumen from the oil sands is to increase the mobility of the cold, very viscous bitumen trapped in the oil sand body and this is achieved by extraction with a hot fluid. For this process to be successful, it is necessary to increase the permeability of the existing tightly packed oil sand body by creating fractures and channels within the oil sands body through which the hot fluid can flow to contact the viscous bitumen. Thus, a condition of fluffed up oil sands or well fractured rubble facilitates the dissipation of the hot fluid evenly through the oil sand body and ideal conditions for the recovery of the bitumen from the sand are achieved without ever moving the sand. Under such conditions the hot fluid can be forced through the porous sand body desirably under the influence of gravity and suitably under gas pressure. The fracturing of the block of oil sands in the room is suitably achieved by selective drilling and blasting of the oil sands block and these operations will normally be carried out from an access drift disposed above the body or from the access drift in the rock strata underlying the oil sands body depending upon the existing requirements.

In a particular embodiment thereof, the present invention provides for the use of explosives to selectively fracture and loosen the oil rich portion of the oil sands body and in particular without disturbing the underlying basal clay beds or low grade lenses of material interspersed throughout the deposits. This is achieved by suitable location of the charges in blasting bores drilled in the oil sands body which bores later serve for the passage of hot fluid into the body. Suitably a light gage liner is disposed in those sections of the blasting bores which pass through low grade upper layer deposits and/or through large lenses of undesired material which are not to be fractured by the explosives. This liner prevents the sloughing off of the side walls of the bore and also provides a means for communication of the hot fluid through the entire length of the holes during extraction of the bitumen with the hot fluid. Suitably, the explosive charges are capable of fracturing the oil sands body at predetermined radii of 2 to 30 feet or more. The blasting of the body to improve the permeability of the body and the blasting of the body to delineate the rectangular body may be combined and achieved at the same time. Alternatively blasting may be achieved by sequentially connecting perforated preformed pipes filled with gravel and swaged to interlock into each other. A porous plug e.g. a styrofoam plug acts as a temporary seal and will dissolve in the presence of petroleum oils. Prepacked explosive charges of selected capacity are inserted between adjacent tubes as desired and connected to a firing wire which wire is taped to the tubular storing being formed when required imperforate sections of tubes can be used or the perforated tubes can be taped over as required. The whole string is pushed or lowered by gravity into the bore hole, adding section by section. Before firing the bore hole is filled with water to increase the effectiveness of the explosive charges.

Exactly the same system may be used for the drainage pipes except that explosive charge and wiring are not required. Perforate or imperforate locking tubes may be raised into position with a hydraulic lift mechanism. Since the bore holes are several hundred feet long and the tubes reasonably flexible, natural distortion and friction holds the units in place. Taping can be applied as required.

In order not to waste tubing a non-locking section is used at the cross over point where the limestone meets the sand body and these tubes can be withdrawn after the main string is in place thus utilizing the natural bore in the rock strata.

In another embodiment of the present invention the fracturing of the oil sands body can be achieved by removal of substantial quantities of sand suitable by the use of stationary or rotating hydraulic jets located adjacent to the drainage pipe inlets. Removal of sufficient sand in this fashion can drastically reduce the blasting requirements as the sand masses will collapse and fracture under their own weight and blasting is only necessary to delineate the room and possibly to loosen the lower layers of the strata. Of course, this method involves the removal of sand from the room and this sand has to be disposed of. It may of course subsequently be partially returned to the mining room after removal of the bitumen values. Thus the richness of oil sand is inversely proportional to its clay content and the presence of a low clay content decreases the tensional strength of the oil sands. Thus, as the rich oil sands are normally found in the lower portion of the oil sand deposit, excellent caving characteristics can be expected in these low clay areas once a void has been created in the basal section of the room. Thus, the blasting is used to control the pillar walls and break the lower course of the oil sand deposit. Once the lower and side courses have been loosed by blasting and a suitable amount of sand has been removed by hydraulic sluicing, the central sand block of the mining room will collapse and cave under its own weight as oil sand deposits have little strength in tension. Adequate fracturing of the oil sand deposit in the room creates conditions which permit maximum recovery of the bitumen values. Therefore, in this embodiment of the invention for fracturing of the body, a portion of the rich oil sands which are normally the weakest and most readily minable portion of the deposit are physically removed for external treatment. Removal of this sand permits caving which creates fractures and voids in the remaining portion of the block in the room thus making it amenable to treatment with the hot fluid for recovery of the bitumen values. In the upper portions of the body where there are beds of siltstone, heavy clays of lean uneconomical oil sands, hydraulic removal of the sand in the lower zones is reduced to so as to minimize any disturbance of this upper area. The strata overlying the void are subjected to collapse at some point in time following the actual mineral removal. Thus, once the natural support is removed by mining the weight of the overlying strata is redistributed. Oil sands have little strength in tension and by selective blasting techniques vertical parting planes are created between the room and the pillar walls and the central mass therefore collapses under ideal conditions for caving into any void areas created by the hydraulic mining. The height and areal size of the void are important factors which influence the distance above the voids that breakage occurs. If sufficient void areas are created by hydraulic mining, breakage will extend upwardly through the block to the overlying shale roof. Breakage is a progressive reaction and if carried to completion results in the room being filled with loosened oil sand material capable of being penetrated easily by the hot fluid. If the upper portion of the oil sand deposit is composed of uneconomical oil sand, then sand removal can be reduced and the breakage is restrained to a lower level. In those cases where uneconomic beds of oil sands are overladen by richer oil sands then the degree of fracturing created is an economic decision. Of course not all of the oil sand in the room is extracted by hydraulic mining and a great cavity is also not created. Only sufficient oil sand is removed from the bottom of the room which will allow the remaining oil sand to fracture and collapse within the void areas created. In general from 10 to 30 percent removal of rich oil sands will create sufficient voids to induce full breakage. The remaining 70 to 90 percent of the block fractures by collapsing into the cavity so formed. Under such an arrangement, blasting requirements are drastically reduced and blasting of the oil sands body is limited to that necessary to delineate the pillar walls and initially loosen the bottom layer.

In the method of the prsent invention, a hot fluid is passed into the oil sands body in the mining room so as to flood the block to a desired level and the residence time of the hot fluid in the room is sufficient to raise the temperature of the block by an amount to cause the bitumen to become flowable with the fluid so that it can be removed as a hot fluid bitumen mixture from the room. The hot fluid may be suitably removed from the room via the perforated pipes, the perforations of which are dimensioned to prevent sand particles from the block passing therethrough. This means that the hot fluid will pass vertically and horizontally through the block to the perforated pipes which is desirable to achieve a maximum removal of bitumen from the block on each pass of the hot fluid through the block.

In one embodiment of the present invention, the hot fluid is introduced into the block from an access drift from the rock strata overlying the oil sands body, the hot fluid passes vertically and somewhat horizontally through the block under gravity and desirably under gas pressure to the perforated pipes which act solely as drainage pipes for the hot fluid bitumen mixture. The passage of the fluid through the block is facilitated by the bores in the block drilled for blasting the sands body inter alia to provide the room and also to provide for fracturing of the block. It will be readily realized that while the hot fluid passes through the block in one particular direction this path can be reversed to ensure that each end of the room will be contacted with fresh hot fluid and thereby improve recovery of the bitumen contained in the block.

In the method of the present invention, the hot fluid bitumen mixtures is desirably withdrawn from the block through perforated tubes. The use of perforated tubes for this purpose besides retaining the sand in the room, also provides for selective extraction of the bitumen from the bitumen rich portions of the oil sands block. In a particular embodiment of the present invention the pipe perforations are not continuous and are selectively placed to coincide with the oil rich portions of the oil sand body previously fractured by the blasting. Thus, the lower portion of the oil sand body resting on the limestone rock may be composed of underclays, barren sands filled with water or gases, gravels, coalseam or other unwanted material. A pipe passing through this unwanted material has solid walls and perforations do not begin until a suitable oil rich grade of sand has been reached. Generally, the drainage pipes are not perforated in those areas where they pass through substantial lenses of clay, low grade oil sand or other unwanted material which in turn has not been disturbed by blasting. Again since much of the upper portion of the oil sand body consists of low grade uneconomical sands, the tops of the perforated pipes which are closed may present an uneven profile as they follow the bottom of the deposits. Thus, by use of the perforated pipes according to the present invention, selective mining of very irregularly zoned oil sand deposits and the rejection of low grade sands and unwanted debris by a combination of proper drainage pipe design, controlled hot fluid flooding levels and selective blasting techniques may be achieved. The pipe perforations may be of any suitable shape and size and/or the pipe may be packed with coarse graded sand, glass beads, steel shot, walnut shells and the like of a size small enough to retain within the oil sands body all pebbles, siltstone lumps and other hard insoluble unwanted debris. Thus, the drainage pipes with properly spaced holes are placed throughout the room and the sand formation between these pipes subsequently fractured by blasting.

A particularly suitable drainage pipe is constructed out of rolls of expanded metal on location underground. This expanded metal tube is wrapped with a strong protective wrapper as it comes of the mandrel of a machine and removal of selected portions of the wrapper as the pipe is being fed into the drilled bore accomplishes the desired interrupted spacing of the perforations to attain the desired rate of flow of the drainage system. A wooden nose plug is attached to the leading end of the pipe to facilitate its passage up the drilled bore hole. By drilling the hole oversize and by increasing the expanded metal overlap whenever it is required to strengthen the pipe, a complete length of drainage pipe can be formed and slid into place, which pipe is cheap enough to be left in place after the bitumen has been extracted from the block in the mining room. Suitably, guide shoes may be attached to the pipe at every twenty to thirty feet to aid its passageway into the drilled bore into position.

In a particularly desirable embodiment of the present invention, the hot fluid is a hot liquid. The hot liquid is suitably introduced into the oil sand block so as to flood the room to a desired level. In a particular embodiment of the method of the present invention, the mining room is separately pressurized with an insoluble gas to maintain flexibility of control of the level of flooding therein. In particular, by controlling the gas pressure in the mining room the level of flooding within the room can be limited, the rate of flow of the liquid through the drainage pipes can be controlled and the transfer of the liquid through a system of conduits or passageways from the room to a separation zone can be effected.

By adjusting the rate of liquid flow out of the room by variation of the pressure, the level of liquid flooding within the room can be controlled at any desired height which ensures maximum liquid contact with the sand in the block and minimzes the effect of channelling. Furthermore, the ability to flood the room provides operational flexibility in that the room can function as the storage reservoir or be called upon to supply extra liquids to satisfy the downstream needs of the process. This non-mechanical movement of the liquid ensures minimum agitation of the liquid during extraction of bitumen from the body and tends to preserve the natural state of the water-wet sand grains. As aforesaid, the natural state of the water-wet sand grains is a very fragile condition and if disturbed can cause irreversible conditions detremental to the recovery of the bitumen. Alteration of the physical configuration tends to result in some oil wetting of the sand grain, which in turn results in contamination of the liquid with additional solids and water present.

The process of the present invention thus provides, in addition to fracturing of the oil sands body with selectively placed explosives, a system of perforated pipes which ensure rapid means of filling and/or draining the room to provide easy passageways through which the liquid can pass. Thus, capped perforated pipes are placed in the holes drilled in the oil sand room from an underlying access drift in the rock strata. These holes are drilled and the perforated pipes placed into position before the intervening oil sand body is fractured by explosive blasting. It is only necessary that the portion of the drilled hole within the oil sand body and the short upper section of the limestone rock be lined with the pipe as in the lower portion the drilled hole within the limestone rock itself will provide an adequate conduit for the liquid.

Displacement of the liquid through the perforated pipes takes place under the effect of the gravity head and room gas pressure. If the pipes are evenly perforated per lineal foot and the permeability of the body is uniform, the flow of liquid is greater in the lower zones of the oil sand body. Thus, since the correct degree of pipe perforations is a function of the gas pressure, gravity head and the artificially created permeability of the surrounding oil sands, it is desirable that these pipe perforations are varied to ensure that it is the upper zones of the oil sand body that enjoy a higher rate of liquid flow thus enabling the progressive depletion of the oil sands deposits from the top down.

As the bitumen content of the upper portions of the oil sands body is depleted, the level of flooding in subsequent cycles is desirably reduced and unnecessary washing of the depleted zones is thereby avoided. This is particularly beneficial with low grade oil sand zones in the upper sections of the deposits which are composed of layers of oil sand interspersed with poorly impregnated layers of material containing abnormal amounts of clay and silt. By instituting a limited number of full flooding cycles in the room and then lowering the level of flooding, readily available bitumen can be "high graded" off in these low grade oil sand zones and at the same time avoid disturbing the bulk of the clay and the silt present in these zones.

A variety of hot liquid flow patterns can be utilized in the method of the present invention. In particular, hot liquid can be forced up through the drainage pipes located in the body to fill the cracks and crevices in the body until a desired pressure or level of filling is reached. A portion of the hot liquid aided by the gas pressure then drains down through the drainage pipes into tunnel storage areas. As the hot liquid increases in bitumen content a portion is removed as oil product and replaced with fresh hot liquid.

An alternative hot liquid flow pattern is to force the hot liquid continuously down through the holes that were used for blasting and practically all of the liquid must travel laterally through the block in order to reach the perforated drainage pipes and thus a minimum amount of mineral material will accompany the fluids as they pass through the block.

A reverse liquid flow pattern can be used in which the hot liquid is forced upwardly through the drainage pipes, laterally through the block and out of the mining room through the drilled blast holes. This flow pattern has the advantage that minimal accumulation of sand occurs in the reservoir beneath the oil sands body, that the flow of clean hot liquid upwardly through the drainage pipes into the sand deposit keeps the pipe perforations from plugging, that the liquid bitumen mixture flowing laterally upwardly through the porous body is substantially free from mineral content and that gravity aids in settling out the mineral particles and any droplets of water. However this flow pattern has the disadvantage that the entire block must be completely filled with liquid during the whole extraction and the advantage of gravity flow is lost; the lower grade upper sections of the block which have the lowest permeability will have to pass the entire liquid volume through its pores and the higher grade lower oil rich sands of the block tend to receive minimum contact with the liquid and thus minimum washing cycles. Since much of the upper portion of the body is composed of low grade deposits, as aforesaid, continual washing of these areas with high grade liquid is a disadvantage.

A third alternative hot liquid flow pattern is to force the hot liquid through the drainage pipes from one side of the room and then force the liquid laterally to drain out of the drainage pipes on the opposite side of the room. This requires a much greater lateral travel distance of the hot liquid in the block and has the advantage of being able to operate the method at any desired level of flooding within the room. This advantage is particularly useful in those deposits where the richer oil sands are located in the lower sections of the body. At various stages one of the above flow patterns may be used or patterns similar thereto.

In a particular embodiment of the present invention the hot liquid is a water-immiscible low-viscosity organic solvent for the bitumen which solvent is desirably anhydrous. In order that the extraction is commercially useful with such a solvent, it is however necessary that the solvent be recovered substantially completely because the solvent employed is usually worth much more than the bitumen recovered. The problem of solvent recovery is magnified because the sand in the block represents so much of the material that is worked and even small percentage losses of solvent in the discarded sand cannot be commercially tolerated. Solvent extraction of the bitumen from the oil sands body involves contacting the oil sands with the solvent to produce a liquid phase of the solvent and dissolved bitumen and a solid phase of sand and then the liquid phase is separated from the solid phase and subsequently the bitumen is recovered from the solvent.

Bituminous sands may be regarded as essentially a compacted mass of water-coated sand particles held together by bitumen which forms a film around each particle. The water immiscible low-viscosity organic solvent, e.g. a light oil having the properties of naphthalene may be heated to form a warm solvent and upon contact with the oil sands, the bitumen fraction dissolves in the solvent forming a compound oil of a specific gravity of less than one, at the same time having a very low viscosity. Thus, in a particularly preferred embodiment of the present invention, the heat of the solvent as well as the dissolving capabilities of the solvent are used to increase the mobility of the bitumen in the sand. The method is normally effected at a low temperature, well below the boiling point of water and usually in the range 90° to 130° F so as to preserve the interfacial skin tension between the water coated sand particles and the liquid hydrocarbon and thereby minimize the co-removal of water from said block with said bitumen by said solvent. The entire process desirably takes place under gas tight conditions which ensures the recovery of the gaseous phase or light ends of the hydrocarbon values. The gas tight conditions are maintained by utilizing the existing rock strata as conduits and pressure vessel containers in which can be moved, stored or processed under desired conditions of pressure and temperature, the slurries, liquids and gases involved in the process. Thus, in this embodiment of the present invention the low temperature solvent, which is immiscible in water, is forced under pressure into the cracks and fractures within the body, the warm solvent moving at a relatively low velocity extracts the bitumen without breaking the liquid film on the water envelope surrounding the sand particle and without disturbing the water filled clay lenses that are prevalent throughout the formation. As the warm solvent only removes bitumen, it is only effective on rich bitumen impregnated sands and by-passes to a large extent the low grade shaly clay containing portions of the body. There is of course some loss of heat into these low grade lenses, but this is restricted to the surface areas and tends to be proportional to the ability of the warm solvent to penetrate the deposits. The ability of the solvent to penetrate, in turn, is proportional to the grade of the oil sand and to some extent to the degree of fracturing created by the blasting. The extraction depends upon the transfer of heat to the cold (40° F) oil sand through which the warm solvent, which is itself not over 130° F, passes. This narrow temperature differential generally requires the solvent to be cycled, reheated, and then recycled many times through the block in the early stages of extraction. As the internal cavities increase in the block, the volume of liquid per cycle increases until a point is reached when a portion of the liquid containing a suitable percentage of dissolved bitumen can be diverted from the recycling to a product oil line and replaced with fresh solvent from a refinery.

In a particular embodiment of the present invention using the solvent extraction technique, as the depletion point of the bitumen in the block is being reached and the block has become more porous and has fully increased in temperature, the temperature of the incoming warm solvent may be increased until there is initial evidence of interfacial breakdown of the water envelopes on the sand particles by the presence of increased water content in the flow of the bitumen-solvent mixture from the block. This increased temperature facilitates removal of the depleted bitumen from the block.

In the process of the present invention using the solvent extraction technique, the pressurized underground solvent storage reservoir may be formed in the overlying rock strata. Thus, pressure developed within the reservoir plus the gravity head will be sufficient to deliver the solvent to the block without the use of mechanical pumps. This reservoir may be provided with a decanting arrangement to remove the solvent bitumen mixture and with a spigoting arrangement to remove settled water and fines. The reservoir may also be fitted with a heat exchanger to maintain the solvent at a desired temperature. Recycled solvent from the block and fresh solvent from surface are fed to the reservoir and by dividing the reservoir into separate compartments solvents containing varying concentrations of dissolved bitumen can be stored separately for more efficient use in the operations.

The solvent extraction process of the present invention is essentially a displacement of a highly viscous liquid bitumen with a low viscosity liquid, namely the solvent, and at the completion of the extraction of the bitumen the block will still be flooded to a large extent with diluted solvent. Substantially all of the solvent must be recovered if the extraction technique is to be economically viable.

In accordance with a particular embodiment of the present invention the solvent recovery from the block is accomplished by steam-sweeping the block or sweeping the block with steam laden hot air until substantially all of the solvent has been recovered. By using hot air or low temperature steam at low velocities the solvent can be distilled off at about 150° F while the liquid envelopes that encase the sand particles are preserved intact. When the liquid water envelopes are fractured there will be a substantial increase in the heat requirements while a substantial quantity of water and clay has to be disposed of. Further, the temperature of the stripping gases can be increased progressively as solvent recovery drops until there is evidence of breakdown of the water envelopes by the presence of increased water content in the recovered solvents.

The recovery of the solvent may also be accomplished by passing hot flue gases through the depleted porous block and these hot gases can be delivered from the surface or can be created underground by combustion in a sealed passageway above the mining room. Low grade hydrocarbon waste products from the refinery can be burned with excess air to form controllably heated flue gases in the passage way and the resulting hot gases may be forced down through the drilled explosive bores and down through the depleted porous sand block. These warm gases evaporate the low boiling solvent and they exit through the perforated pipe system into the lower passageways where water cooled condensers or sprays will convert the bulk of the gaseous solvent in a liquid form which is then recycled. The residual flue gases are passed to the surface for final scrubbing before discharge.

An alternate source of fuel is the low grade bitumen deposits present in the upper layers of the oil sand body which may be ignited to create the desired hot flue gases. This system is howevermore difficult to control and may result in the combustion of a portion of the desired solvent as well as possibly reaching local temperatures that may destroy the water envelopes and therefore increase the quantity of connate water including the entrapped fines. Such a condition tends to plug the pores of the block, and restrict the recovery of the solvent from the block.

In the solvent extract procedure, because the entire recovery is desirably in a closed pressurized circuit, it is possible to use low boiling point solvents such as gasoline or even liquified petroleum gases all of which are effective diluents and are easily recoverable during the solvent stripping stage. Alcohols may also be used.

It is well known that liquified petroleum gases or light oils, with boiling points in the range of 70° to 150° C, which are saturates of aliphatic composition, are capable of dissolving the oil portion of the bitumen to form a combined oil of substantially lower viscosity. These aliphatic liquids leave untouched the major proportion of the undesirable asphaltenes which are insoluble in the extraction solvent of saturates and which tend to remain deposited on the sand particles in the block. The asphaltenes represent about 20% of the bitumen by weight and the remaining 80% of the bitumen is a maltene portion which is composed of the oily constituent of the bitumen. In the maltene portion approximately 25% of the oil are aromatics which are capable of dissolving the asphaltenes.

The use of the light oily mixture containing a high proportion of saturates, such as naphthenes or straight run gasoline, selectively dilutes the oily portion of the bitumen and produces a combined oil of lower viscosity which contains some aromatics. When the aromatic content of the recycled combined oil is about 20%, the oil is removed as product oil and replaced with fresh solvent. By the use of such solvents, approximately two thirds of the asphaltenes remain in the body and only one third are extracted in the product oil. This is desirable as the asphaltenes are costly to remove in the refinery from the extracted bitumen and their sulphur content is approximately double that of the oily portion. Major proportions of the asphaltenes can be left in the sand block by the use of liquified petroleum gas such as propane or butane as the extraction solvent. This method is practical as suitable pressure containers are provided in the rock formation which are capable of withstanding pressures of up to 600 psi which are necessary to keep the gases in liquid form during the extraction cycle. Solvent recovery is easily achieved by reducing the pressure and allowing the solvent to come off as a gas followed by an airsweep. The above two methods can be combined by using the light oil hydrocarbon mixtures to remove the bulk of the oily constituents followed by a wash cycle of liquified petroleum which in turn is followed by an airsweep to complete the cycle.

In using the solvent extraction technique, the bitumen solution removed from the body is allowed to settle in a pressure vessel whereby any water and sand present in the solution is separated therefrom by decantation and the solvent removed from the bitumen by flash evaporation by releasing the pressure in the vessel, the solvent being condensed and recycled to a reservoir from which the room is flooded therewith.

In a particular embodiment of the solvent extraction process of the present invention, the solvent is heated to a much higher temperature which will break down the liquid water envelope surrounding the sand particles in the block and the sand particles are flushed from the block together with their fines. While this procedure initially will produce a dirtier product oil, it greatly speeds the rate of recovery and in practice this initial step may be used until about 20 to 30% of the bitumen has been removed leaving substantial cavities in the block. At this point in the process the temperature of the solvent is reduced so that the remaining liquid water envelopes remain intact and the cleaner more desirable oil is obtained from the block.

In another embodiment of the present invention the hot liquid is hot water which is fed into the room at a high temperature and at a high pressure to form an emulsion of water and bitumen which is removed from the roomm through said drainage pipes. In such a process a pressurized underground hot water storage reservoir is formed in the overlying rock strata where makeup water, steam and other reagents from the surface can be added and mixed and passed to the mining room. Gas pressure developed within the reservoir plus the gravity head is sufficient to deliver the hot water to the block without the use of mechanical pumps, the reservoir being provided with a decanting arrangement to scavenge any floating residual traces or oil and a spiggoting arrangement to remove any accummulation of settled minerals. The circulating hot water may have emulsifying additives or surfactants or pH additives therein as may be required. Thus, in the process using hot water as the hot liquid, the hot water suitably at a temperature from 300° to 500° F under pressure is passed into the mining room and forced into the fractures of the body to contact the cold bitumen according to one of the flow patterns described heretofore. The recovered liquid is a hot oil-water emulsion containing some fine material. The quantity of mineral removed from the emulsion depends to a large extent on the areal extent of the openings in the drainage pipes and their size and shape as well as the velocity of the emulsion passing through these openings. The velocity of the oil-water emulsion may be controlled by the gas pressure maintained in the mining room, the area of the pipe openings and the black pressure of the water in the passageway into which the drainage pipes discharge. In the process each room is individually pressurized with an insoluble gas to give flexibility of control and by this means it is possible to maintain the aqueous liquid at elevated temperatures or release steam within the room to produce localized agitation and rupturing of the films on the sand particles through a boiling action or control the level of flooding within the room or carry out the transfer of the liquid emulsion from the room to a sand extraction zone and subsequently through an oil-water separation zone without the use of mechanical equipment. The gas pressure may also be used to control the rate of flow of oil-water emulsions through the pipe drainage system and aids in resisting the overburden loads as roof stresses change during the extraction procedure.

The superheated hot aqueous solution suitably at a temperature from 300° to 500° F is permitted a suitable residence time for the heat to dissipate and penetrate the block in the room which will result in an overall drop in the temperature of the solution and a subsequent temperature rise on the interfacial surface layers of the oil-sand in contact with the hot aqueous solution. The lowering of the room pressure at frequent intervals below the vapour pressure of the liquid results in a small release of steam. The heated water film surrounding the sand grains tend to vapourize and rupture the bitumen envelope and the boiling action results in the creation of minute fractures at the interface between the hot liquids and the oil sand block thus exposing fresh layers of unheated oil sand. The sand particles remain water-wet while the bitumen forms a hot liquid oil-water emulsion of low viscosity which may be displaced out of the oil sand body under gravity and gas pressure. Essentially all of the oil-water emulsion travels laterally through the body in order to reach the perforated drain pipes. When the velocity of this liquid movement is kept at a very low level, a minimum amount of mineral material will accompany the draining liquid as the preferentially water-wet silts and clays will tend to adhere to the water-wet sand particles in the block. By this process the natural water-wet condition of the mineral fraction in the block is maintained and there is no violent agitation whereby mineral matter can be made oil-wet mechanically. Further, there is no opportunity for evaporation of water from the mineral surfaces to occur which would permit an oil-wet sand condition to form. As aforesaid in discussing the prior art process, this condition is undesirable and reduces the recovery of the bitumen.

Further, by utilizing a higher velocity of liquid inflow during the flooding of the mining room, the intersticies of the sand particles near the pipe perforations are swept clean of any deposited silts and clay and high permeability of the sand block near the perforated pipes is maintained during subsequent draining cycles. Liquid cycling operations are continued until the recovery of the bitumen values drops to an economic cut off point. To ensure the maximum recovery of the bitumen, suitable surface active agents and/or pH controlling reagents are added to the hot water during the flooding cycle which tend to improve the yield by decreasing the interfacial tension between the bitumen and the water. The greater the degree of fracturing and subsequent agitation by ebullient boiling, the lower will be the number of constrictions in the pore channels of the block and therefore the higher the recovery rate.

As with the solvent extraction technique, as the bitumen content of the upper portion of the oil sands body is depleted the level of flooding in subsequent cycles can be reduced thereby avoiding unnecessary washing of the depleted zones.

In a particular embodiment of the present invention the residual block in the mining room after removal of the bitumen is a heated block and the heat values may be recovered by flooding the block with cold make-up water. This recovery of heat values from the depleted block requires a very low velocity of liquid flow during drainage in order to minimize removal of clay of silt from the interstices of the sand block and to provide a residence time for the transfer of heat. Following the removal of the heat value the block may be used as a pressure sand filter for the removal of silt and clay from the waste water which is separated from the oil in a subsequent separation step. Thus, the method of the present invention using a water extraction technique provides for the underground disposal of the silted waste products in a depleted block and the subsequent recovery of process water by utilizing the depleted block as a pressure sand filter. Of course the recovery of heat values and the clarification of the water may be combined into a single step. By forcing the contaminated separated water through the residual porous block, a substantial portion of its fines content can be removed through some portion of −2 micron size clays will be carried through with the drainage water. This carryover can be minimized in accordance with the process of Canadian Pat. No. 926,885 by the addition of water-soluble high molecular weight polymer as fines retention agents.

In a further embodiment of the present invention, the water extraction technique is modified by the presence of a preferably water-immiscible organic solvent for the bitumen. It has been found that the presence of such a solvent, for example a petroleum distilate, at a solvent-bitumen ratio of about 1:1 by volume in the water increases the recovery of bitumen values and lowers the required liquid phase feed temperatures to the block to about the 200° to 300° F range with the oil-water emulsion liquid being recovered in the range 100° to 150° F. Thus, the loss of some solvent can be compensated for by a lower heat requirement. The solvent may be a liquid hydrocarbon solvent preferably a hydrocarbon solvent boiling in the range 100° to 400° F, suitable examples of which are coker naptha and gasoline. Because the entire process is in a closed pressurized circuit, it is possible to use low boiling point solvents such as gasoline or even liquified petroleum gases all of which are very effective solvents and are easily recoverable during the solvent stripping stage.

Separation of both water and mineral solids from the bitumen is necessary for most ultimate uses of the bitumen such as upgrading in conventional refining operations. In the process of the present invention the formation of froth is avoided at all stages by the use of pressure vessels located underground in the limestone strata to carry out the oil separation step in the conditions of elevated temperature and pressure within a closed circuit.

In the method of the present invention using hot water extraction, the very hot 400° to 500° F water circulating through the block reduces the viscosity of the bitumen to form an oil-water emulsion which at about 300° F will have a viscosity about equal to that of water and a bitumen content of about 30%. To this emulsion is added a solvent at a solvent-bitumen ratio of about 1:1 by volume to dissolve the bitumen particles and to form a combined oil. The diluent or solvent, which is desirably a petroleum distilate, is suitably added to the emulsion as it leaves the mining room and is mixed during passage of the emulsion to a sand separator. The diluent can be a liquid hydrocarbon solvent such as coker naphtha having a boiling range of 100° to 400° F and further a demulsifying agent is desirably added thereto to lower the interfacial tension between the bitumen and water particles. Of course, when the hot water contains a solvent then there is no need to add further solvents on exiting from the mining room. However, a demulsifier is added and it is heated to about 300° F to prepare it for separation.

In a particular embodiment of the present invention in the water extraction method with or without the solvent, the emulsion is withdrawn from the room and passed to a sand separator at high temperature and under high pressure and at a velocity sufficient to maintain the sand particles of less than 100 micron size in suspension. The sand particles over 100 micron size are separated in said separator. The emulsion is passed from the sand separator to an oil-water separation chamber. The diluent is added to the emulsion after leaving the room and before passage to the separation chamber in an amount sufficent to form a combined oil of density less then 1. The oil, water and fine sand solids are allowed to separate under gravity settling, under conditions of high temperature and pressure, the fines solids are removed as a sludge, at least part of the water is removed from the separation chamber, and the bitumen is removed from the separation chamber as a fluid under pressure as hot liquid for passage to the surface for refining. In a particular embodiment of the invention, the diluent is added to the emulsion as it passes from the sand separator to the separation chamber. Alternatively the diluent may be added to the emulsion as it passes to the sand separator. Desirably a back pressure is maintained in the separation chamber to provide for non-turbulent removal of bitumen from the separation chamber and the subsequent filling up of the separation chamber with further emulsion for separation. Suitably the sand is removed from the sand separator and passed to a drying vessel where it is flash dried by reducing the pressure in the drying vessel. The water separated from the emulsion is desirably recycled to a reservoir for further flooding of the mining room. As aforesaid recycled water or fresh water for flooding the mining room is suitably heated by passing through the sand block of a mining room from which the bitumen has been previously exhausted and recycled water can be clarified by slow passage through the block in the mining room from which the bitumen has previously been exhausted.

The method of the present invention offers the desirable possibility of utilizing the underground strata as a pressure vessel thereby allowing an oil-water mineral separation step under elevated temperatures and pressures with large volumes of liquid. By the use of underground rock to contain the gas and liquid pressures, it is possible to construct very large pressure vessels at an economical cost and operate those high pressure vessels under safe conditions. It is this possibility of containing the pressure by the surrounding rock that makes it economically possible to produce a multiplicity of large vessels, whereas to duplicate the same arrangement on the surface would render the process extremely expensive and economical undesirable. To achieve maximum quiescence and to permit prolonged settling periods of up to 24 hours or more, the separation is preferably conducted as a batch process. Thus, the oil-water separation step takes place in a quiescent zone by carrying out the process on a batch basis in a multiplicity of pressure chambers. The oil, by virtue of its lower specific gravity, will rise to the top of the chamber while the mineral fines in the heavier water will occupy the lower portion of the chamber. Settling periods of up to 24 hours or more are possible. The combined oil is decanted off and sent to the refinery as a hot liquid where the solvent is recovered by distillation and returned to the process. Separation of the water from the bitumen requires a solvent addition and the inclusion of a de-emulsifying agent to provide essentially complete separation. The hot water is steam flashed by dropping the pressure to recover any residual traces of solvent and the water then pumped as a hot liquid to the hot water storage reservoir. The settled mineral slimes may be disposed of by pumping them to a depleted porous sand bed.

In the solvent extraction method, the cooled 90° to 100° F solvent bitumen mixture exiting from the room and passing to a separator for the separation of sand thereof suitably has an emulsifier added and is heated to about 300° F in preparation for the settling of the sands.

It will thus be seen that in a preferred embodiment of the present invention the conduits, pressure vessels and storage vessels are all formed from the rock strata, which is highly desirable both economically and for efficency for example, the pressure storage reservoirs from which the liquids can be added to or removed from the mining room may be created by blocking off the ends of both the overlying or underlying access drifts. Further the pressures and flow of fluids in the process are provided primarily by gravity and gas pressure which again is desirable both economically and commercially.

In a further embodiment of the present invention the hot fluid may be a hot gas such as steam, air, carbon dioxide, nitrogen or flue gases which are heated externally and then forced into the mining room. These hot gases moving through the block in the mining room liquefy and partially gasify the bitumen in the oil sands block and carry the liquid and gaseous products to the perforated pipes for recovery. The flue gases can be heated on the surface but preferably are heated in a sealed upper access drift which is utilized as a combustion chamber. In the combustion chamber a suitable fuel is burned to produce a large volumen of hot flue gas under high pressure. Such fuels include waste refinery products, liquid pitch, coal and pulverized coal.

It is clear that in the method using hot gases these hot gases can be produced without the use of heat exchangers and the products of combustion can pass directly from the combustion chamber into the prefractured block through the existing bore holes. The use of high-ash containing fuels may be limited to the latter stages of recovery in order to prevent early blocking of the passageways in the block.

The present invention will be further illustrated by way of the accompanying drawings in which:

FIG. 1 is a schematic vertical section through parts of an oil sands deposit showing the method of in situ recovery of bitumen from oil sands according to a preferred embodiment of the present invention.

FIG. 2 is a plan view of the oil sands body showing the room and pillar method of separation thereof;

FIG. 3 is a schematic section taken along the line B—B in FIG. 2 showing the disposition of the bores holes and the explosive charges for selectively fracturing the block in the mining room in FIG. 2;

FIG. 4 is a section taken along the line A—A in FIG. 2 showing the disposition of the drainage pipes in the block in the mining room in FIG. 2; and

FIG. 5 is a schematic representation of the oil separation technique according to a particular embodiment of the present invention when hot water is used as the extraction liquid.

Referring to the drawings, and particularly to FIGS. 1, 2 and 3 an access mining shaft 1 is sunk through muskeg 8, glacial till 9 overlying shale rock 11 and oil sands deposits 21 into the underlying limestone rock 24 using conventional mining techniques.

From this vertical shaft 1 are driven horizontal access drifts which are working tunnels or passageways. One access drift 12 is driven above the oil sand deposit 21 in the shale rock 11 and horizontally spaced access drifts 22 and 25 (FIGS. 3 and 4) are driven in the limestone rock 24 below the oil sands deposit 21. These horizontal access drifts 12, 22 and 25 can be bored in the limestone by tunneling machines using conventional mining methods.

A pressurized liquid storage reservior 6 and a compressed air reservoir 7 are formed directly in the overlying shale rock 11, the reservoir 6 being equipped with heat exchangers (not shown) so as to raise the temperature of liquid therein. Liquid is fed from the surface to the reservoir 6 via line 2. Steam to heat the heat exchanger (not shown) or added directly in the reservoir 6 is fed via line 3 and the reservoir receives recycled hot liquid via line 4. Pressurized air is fed to the compressed air reservoir 7 through line 10.

Referring particularly to FIGS. 2, 3 and 4 from the access drift 12 drilled holes pass through the overlying shale rock 11 into the block of oil sands 21 contained within the pillar wall 19 of the mining room. Explosive charges 20 which can vary in blasting capacities are placed in preselected positions in the drilled holes. In particular, from the material obtained from the drill hole the composition of the various levels of the block through which the drilled holes pass is ascertained and from this information the size of the explosive charge and its location are determined. Thus for example the basal underclays 27 and low grade material 26 are not to be disturbed and explosive charges are not placed in these zones. By this method selective fracturing of the oil sand deposit 21 takes place and the pattern being repeated at regular intervals along the full length of the access drift 12. The pillar walls 19 of undisturbed oil sand are created by avoiding explosive fracturing of the oil sands in these areas. Thus by selective blasting it is possible to produce the mining room in the oil sands 21 enclosed by the pillar walls 19. Further, the block of oil sands 21 in the mining room is fractured in a selected manner.

Before such fracturing light weight metal or plastic pipes 17 which are capable of some bending or deforming without breaking are placed into a series of holes drilled into the oil sands deposit from the passageways 22 and 25. These pipes are finely perforated and wrapped in a plastic tape. The rate of liquid flow into the pipes 17 at any given elevation is substantially controlled by the area of exposed perforated pipes in the section passing through the given elevation. The degree of perforated pipe exposure at any given elevation is determined by the amount of plastic tape wrapping that has been removed from the pipe 17 during installation. In the basal underclay area 27 and the low grade material area 26 tape covering on the pipe is left intact and the pipe in these areas is essentially imperforate. Also, no pipe is required in the underlying limestone as the drilled holes for the pipes act as satisfactory conduits to the drifts 22 and 25. Selective draining of the oil sand block 21 thus takes place with the pattern being repeated at regular intervals along the full length of the passageways 22 and 25. A special fence of drainage pipes 16 is located within the pillar walls 19 to act as a barrier for any liquids that might find a natural channel or fissure through the pillar walls 19. These perforated pipes in the locations 16 are more closely spaced and have a maximum amount of tape removed to ensure good drainage characteristics and thereby tend to trap any errant liquid. Subsequently, this barrier fence 16 is used to drain the hot liquid from the pillar walls 19 during subsequent removal of the bitumen values from the pillar walls 19.

Initially, the holes for the pipes 17 are drilled and the pipes 17 are put into position. The passageways 22 and 25 are sealed with barrier doors 23 to form tunnel reservoirs. The drill holes 18 are then drilled, the blast charges 20 placed therein from the passageway 12 and the oil sand body 21 is fractured in between the perforated pipes 17 and also the pillar walls 19 and the block are delineated to form the mining room. The drift 12 is sealed with barrier door 15 to form a further reservoir and the system is now ready for the flow of hot liquid.

The hot liquid can flow in several patterns, one pattern is the passage of the heated liquid from the liquid reservoir 6 into the drift 12; a cushion of air from the compressed air reservoir 7 via line 13 is also introduced into the drift 12. Surface active agents and pH agents desirable to control interfacial tension between the liquids are added at this time. The hot liquid flows into the block of oil sand deposit 21 through the blasting holes 18 under gravity and gas pressure to penetrate the cracks and fissures in the fractured block. When the upper section of the block contains low grade material it is advisable to line this upper section of the blasting holes **18** with light gage pipe to avoid washing out or the erosion of the sidewalls of the holes **18**. Thus the liquid does not contact the biumen until it has reached fractured zones. The hot liquid reduces the viscosity of the cold bitumen in the block by the heat and when the liquid is solvent by the dissolving power of the solvent to form a mixture and when the hot liquid is water, to form an oil-water emulsion. These liquids are displaced laterally through the block to the drainage pipes **17** and then to the tunnel reservoirs **22** and **25** from which they can be passed to the reservoir **6** for recycling to the body or to an oil separation zone **28** to obtain production oil. The rate of flow of the hot liquids through the block is determined by gravity, gas pressure, the permeability of the block and the back pressure of the liquid filled drainage pipes **17**. Some sand particles will settle in the lower tunnel reservoirs **22** and **25** and these reservoirs require flushing at regular intervals to remove the sediments.

An alternative pattern is the reverse of the above procedure where the hot liquids are fed into the tunnel reservoir **22** and **25**, forced under pressure up through the pipes **17** and out into the cracks and crevices of the fractured block. The low viscosity liquids rise through the block to collect in the tunnel reservoir **12** from which the liquid can be removed for recycling or oil separation as required.

A further pattern, is to feed the hot liquid into the tunnel reservoirs **22** and **25**, force the liquid up through the pipes **17** to fill the block via the cracks and crevices until the desired pressure or level of flooding of the body is reached. The pressure is then applied to the liquid in the block which added by gravity returns the enriched hot liquid through the pipes **17** to the reservoirs **22** and **25** for transfer to the reservoir **6** or as production oil. The reservoirs **22** and **25** always remain full and are equipped with heat exchangers (not shown) to add heat to the liquid particularly on recycling. Further, regular flushing is required to remove settled sediment in the reservoirs **22** and **25**.

A still further flow pattern, is to pass the hot liquid from the reservoir **22** through the pipes **17** into the block and force the enriched hot liquid to move laterally across the block and drain out through the drainage pipes **17** to the reservoir **25**. The enriched hot liquid is now reheated and recycled into the reservoir **22** until it achieves a satisfactory content of bitumen. This pattern has a major advantage that the level of flooding in the block may be controlled, operation is continuous and the lower portions of the block which contain the bitumen richer sand are continuously rewashed. This flow pattern is of course reversible. These patterns can be used as desired during the various phases of development of the oil sands body **21**.

When the recovery of bitumen from the block falls below an economic level the room is given a final wash cycle with substantially clean hot liquid and both the room and the tunnel systems are completely drained of liquids which are now transferred to the reservoir **6**. Any remaining solvent within the room and tunnel reservoir is stripped off using steam or hot air or hot flue gas. When the mining has been completed the mined out block of oil sands **21** consists of porous sand containing 25 to 30% porosity.

The enriched liquids obtained may be further heated and/or have solvent additions to form the combined oil-water mineral emulsions.

The final water and separation step takes place in a quiescent zone preferably on a batch basis using a multiplicity of pressure chambers. The combined oil by virtue of its lower specific gravity will rise to the top of the chamber while the mineral fines and heavier water occupy a lower portion of the chamber. Settling periods of up to 24 hours or more can be achieved. Compound oil is decanted off and sent to the refinery as a hot liquid where the solvent is recovered by distillation and returned to the process. The hot water is steam flashed by dropping the pressure to recover residual traces of solvent and the water then pumped as a hot liquid to the hot storage reservoir.

A typical separation for the combined oil is shown in FIG. **5** when hot water is used as the hot liquid.

Thus the hot bitumen water emulsion at 300° to 500° F drains under gravity and gas pressure through pipes **17** into reservoir **22**. From reservoir **22** the hot oil-water emulsion is fed via line **41** to the oil-sand separation chamber **29** and is mixed enroute with a 1:1 diluent bitumen volume ratio of hot recycled diluents at 2 temperatures of 300° to 500° F. The diluent and bitumen combine to form a hot combined oil solution with a specific gravity of less than 1. All or substantially all of the finely divided bitumen particles combine with the diluent to form an oil phase leaving substantially all the mineral residue which remains water wet in suspension in the water phase. While some finely divided mineral particles of silt and clay may report to both the oil and water phase, substantially all sand particles having a size greater than 100 microns remain water wet and these particles may therefore be separated in chamber **29** and discarded. The addition of wetting agents makes it possible to obtain mineral particles properly wetted with water and to reduce the absorption of oil by the clay particles present.

In the sand separation chamber **29** a flow velocity rate is maintained to keep in suspension substantially all the particles of sizes less than 100 microns and to settle out of the water phase substantially all sand particles that are greater than 100 microns in size. Standard conventional back washing of the settled sand bed may be carried out if desired.

The coarse settled sand in chamber **29** is removed by adding high pressure water through conduits **30** to sluice a mixture of sand and water up through conduits **31** and **32** into a sand drying chamber **33**. By reducing the pressure in the sand drying chamber **33**, steam is released which forces the hot water out of the sand through conduit **34**. By air sweeping the sand bed the balance of the moisture can be removed by evaporation. The dry sand can then be discharged from valve **35** onto conveyor **36** for disposition to the surface. If desired the coarse sand can be pumped to the surface as a slurry and the drying step carried out on conventional filters or in pressurized sand drying chambers. The sand drying step in chamber **33** is a batch process.

The combined oil and water phase together with any mineral slimes are transferred via line **37** into an oil water separation chamber **28**. The separation of the oil phase from the water phase is accomplished by the addition of de-emulsifying agents followed by prolonged settling at elevated temperatures and pressure. Interfacial surface tension between the oil phase and water phase are diminished by high temperatures and the addition of the de-emulsifying agent and therefore given sufficient and ideal quiescent conditions, the majority of the mineral particles precipitate out of both oil and water phases and settle in the bottom of chamber 28 as a sludge. In the meantime, the combined oil phase rises to the top of chamber 28 and the water phase occupies the lower portion of chamber 28. To achieve maximum quiescence and to permit prolonged settling periods of up to 24 hours or more, the separation stage is a batch process. A multiplicity of pressure vessels in the limestone strata is therefore provided. The sand settled in the chamber 28 is removed via line 38 and the hot clean oil is forced out of the separation chamber by means of a fluid under pressure and passes through line 39 to the surface as feed to a refinery where the solvent is removed by distillation and recycled to the process. The settled slimes removed through line 38 may be further treated to recover any residual bitumen or solvent before being pumped to the depleted sands bed for disposal.

The settled water passing out of the oil separation chamber 28 after the oil is passed through line 40 and line 34 to the hot water storage reservoir 6 as a hot fluid under pressure. Any residual solvent in the water can be recovered by steam flashing followed by condensing.

The movement of liquids and slurries throughout the whole process system is accomplished by controlled displacement under forces of gravity and pressure without the use of mechanical pumps and great care is taken to avoid any major pressure drops in the system which will release steam and thereby cause a separation of the careful establishment of oil and water phases.

On completion of the removal of the bitumen from the mining rooms in sequence the oil sands body will have a series of spaced pillar walls 19 which can be subsequently treated in a similar manner for the removal of bitumen through the tubes 16.

The process of the present invention in its various embodiments is capable of achieving the following effects:

(a) to provide for the economic recovery of hydrocarbons from oil sands deposits,
(b) to extract bitumen values from oil sands deposits at any depth of burial without disturbing the overburden,
(c) to eliminate the mechanical problem caused by severe climatic conditions,
(d) to maintain the natural water-wet condition of the oil sands until the bitumen values have been extracted,
(e) to eliminate contact with unsaturated air and thereby avoid any evaporation of the water film on the sand grains,
(f) to maintain conditions of high pressure and high temperature during the entire extraction and separation process,
(g) to eliminate all mechanical handling until the bitumen values have been extracted,
(h) to utilize only gravity and gas pressures to remove fluids slurries or gases,
(i) to eliminate the formation of froth,
(j) to utilize existing rock strata for conduits, passageways and pressure vessel containers,
(k) to selectively mine the irregularly bedded oil sands,
(l) to create selective fractures within the oil sands deposits,
(m) to selectively water flood fractured zones,
(n) to thermally rupture the bitumen envelopes surrounding the sand grains,
(o) to provide for the separation of oil-mineral water fractions underground,
(p) to deliver separated oil to the surface as a hot liquid,
(q) to deliver a separated water to an underground storage reservoir as hot liquid,
(r) to provide for the underground disposal of all silty and clayey waste products,
(s) to provide for the clarification and reuse of process water,
(t) to provide an underground pressurized water storage reservoir which will function as a steam and water mixing chamber as an oil and mineral scavenger and as a storage vessel for hot water,
(u) to provide for the recovery of heat values from the depleted sand beds,
(v) to provide for the thermal drying underground of coarse sand particles,
(w) to deliver sand to the surface in a dried condition,
(x) to selectively remove only the bitumen,
(y) to selectively remove oily portions of the bitumen only, and
(z) to recover light hydrocarbon ends present in the formation.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of in situ extraction of bitumen from an oil sands body which comprises sinking an access shaft through the oil sands body, driving a plurality of access drifts in the rock strata adjacent said oil sands body at least one access drift being in the rock strata underlying the oil sands body, providing at each of a plurality of locations spaced longitudinally along each access drift a plurality of bores extending in a fan-shaped pattern transversely of said access drift into said oil sands body to provide transverse rows of bores spaced longitudinally along said body in the direction of the access drifts, alternate transverse rows of bores defining rows of inlets and outlets for passage of fluid through said body, said outlets being in access drifts underlying said body, providing perforated pipes in those portions of the bores defining the outlets in said body, the perforations in the pipes being dimensioned to prevent said particles from said body passing therethrough, increasing the permeability of the body by causing fracturing of the body through the inlet bores to provide a fractured block of oil sands in said body defining an enclosed mining room capable of retaining liquids and gases under pressure surrounded by undisturbed solid pillar walls on all four sides of said room, sealing the ends of the access drifts to provide a closed reservoir system capable of delivering and removing fluid through said inlets and outlets and associated access drifts, flooding the block at all elevations at substantially the same time via said inlets at a temperature and for a residence time sufficient to raise the temperature of the block by an amount to cause the bitumen to become flowable with said fluid and removing the fluid-bitumen mixture so formed from all desired levels in said block substantially at the same time through said outlets and associated access drift and separating said bitumen from said fluid.

2. A method as claimed in claim 1 in which the bitumen content of various layers of the block through which each bore forming the outlets extends is determined and perforated pipes are inserted into said bores,

the size, number and disposition of the perforations in the pipe being such as to selectively remove bitumen from the bitumen rich layers of the blocks.

3. A method as claimed in claim 1 in which each bore has a length determined by the bitumen content of the upper layers of the block so as to selectively remove bitumen only from bitumen rich portions of the upper layers of the block.

4. A method as claimed in claim 1 in which the block is fractured by removing, by means of high pressure hot water jets, the lower 20 to 30% by volume of the sand in the block whereby the upper portions of the block collapse to cause said fracturing.

5. A method as claimed in claim 1 in which the pillar walls of the room also contain perforated tubes for collecting fluid passing into said walls from said room, the fluid being removed from said room for recovery of bitumen therefrom.

6. A method as claimed in claim 1 in which the fluid is a hot liquid.

7. A method as claimed in claim 6 in which the room is flooded to a level only sufficient to remove bitumen from the bitumen rich layers of sand in said block.

8. A method as claimed in claim 7 in which the level to which the extent of flooding of the room is controlled by the rate of flow of liquid into the room and removal therefrom and also by a gas under pressure passed into said room.

9. A method as claimed in claim 6 in which the liquid is a water-immiscible low-viscosity organic solvent for said bitumen.

10. A method as claimed in claim 8 in which the organic solvent is introduced into said room under high pressure and at a temperature not in excess of 130° F for a residence time sufficient to raise the temperature of the sand in the block to be in the range 90° to 130° F whereby to primarily remove bitumen from said block with a minimum of removal of water.

11. A method as claimed in claim 10 in which removed bitumen solution is heated to 250° to 400° F, allowed to settle in a pressure vessel whereby any water and sand present in said solution is separated therefrom by decantation and the solvent removed from the bitumen by flash evaporation by releasing the pressure in said vessel, the solvent being condensed by recycled to a reservoir from which the room is flooded therewith.

12. A method as claimed in claim 9 in which the residual solvent in said room when all the recoverable bitumen has been removed therefrom is recovered by sweeping the room with an inert hot gas.

13. A method as claimed in claim 12 in which the hot gas is steam or hot air admixed with steam.

14. A method as claimed in claim 12 in which the hot gas is a flue gas generated by burning a combustible product in an upper tunnel and feeding the gas through blast holes used in fracturing the block or by ignition of low grade bitumen deposits in the upper portion of the block.

15. A process as claimed in claim 9 in which the solvent is fed into said room at a high temperature sufficient to break down liquid water envelopes surrounding the sand particles and flush them from the block together with their fines until 20 to 30% of the bitumen has been removed thereby providing substantial cavities within the block, the temperature of the solvent being then reduced to a temperature not in excess of 130° F.

16. A method as claimed in claim 9 in which the solvent is selected from liquified petroleum gases or light oils of boiling points from 70° to 150° C which are of saturated aliphatic composition.

17. A method as claimed in claim 6 in which the liquid is water which is fed into said room at a high temperature and at a high pressure to form an emulsion of water and bitumen which is removed from the room.

18. A method as claimed in claim 17 in which the pressure in the room is periodically reduced to cause ebullition of the water and generation of steam whereby to enhance rupture of bitumen envelopes around the sand the pressure being periodically increased to condense the generated steam.

19. A method as claimed in claim 17 in which the flooding and subsequent removal and separation of the bitumen from the water is at a pressure sufficient to substantially avoid the presence of froth in the emulsion.

20. A method as claimed in claim 17 in which an inert gas pressure is maintained in the room to assist in drainage of the emulsion therefrom.

21. A method as claimed in claim 17 in which the emulsion is removed from said room at a low velocity to minimize sand entrainment in said emulsion.

22. A method as claimed in claim 17 in which the water is passed into said room through said perforated pipes at a high velocity to effect flooding of the room to thereby sweep the interstices of the sand particles located near the pipe perforations essentially clean.

23. A method as claimed in claim 17 in which the water contains at least one of an emulsifying agent and a pH controlling agent.

24. A method as claimed in claim 17 in which the water contains an organic solvent for the bitumen.

25. A method as claimed in claim 17 in which the emulsion withdrawn from the room is passed to a sand separator at high temperature and under high pressure and at a velocity sufficient to maintain sand particles of less than 100 micron size in suspension, separating sand particles of over 100 micron size in said sand separator and passing of emulsion from said sand separator into an oil-water separation chamber, adding diluent to the emulsion after leaving said room and before passage to said separation chamber in an amount sufficient to form a combined oil of density less than 1, permitting separation of the oil, water and fine sand solids by gravity settling under conditions of high temperature and high pressure, removing the fine solids as a sludge from the separation chamber and at least part of the water and removing bitumen from the separation chamber by fluid under pressure, as a hot fluid for passage to the surface for refining thereof.

26. A method as claimed in claim 25 in which the diluent is added to the emulsion as it leaves the mining room and is mixed during passage of the emulsion to the sand separator.

27. A method as claimed in claim 26 in which the diluent is added to the emulsion as it passes from the sand separator to the separation chamber.

28. A method as claimed in claim 25 in which a back pressure is maintained in the separation chamber to provide for non-turbulent removal of bitumen from the separation chamber and the subsequent filling up of the separation chamber with further emulsion for separation.

29. A method as claimed in claim 25 in which the sand is removed from the sand separator and passed to a drying vessel where it is flash dried by reducing the pressure in the drying vessel.

30. A method as claimed in claim 25 in which the water separated from the emulsion is recycled to a reservoir for further flooding of a mining room.

31. A method as claimed in claim 17 in which recycled water is clarified by slow passage through the sand in a mining room from which the bitumen has previously been exhausted.

32. A method as claimed in claim 31 in which the recycled water or fresh water for flooding the mining room is heated by passage through the sand of a body of a mining room from which the bitumen has been exhausted.

33. A method as claimed in claim 1 in which conduits, pressure vessels and storage vessels are all formed out of the rock strata.

34. A method as claimed in claim 1 in which pressures and flows of the fluids are provided by gravity and gas pressure.

35. A method as claimed in claim 1 in which the block is selectively fractures to fracture essentially only those portions which are oil rich by selective placement of blasting charges in balsting bore forming the inlets, those portions of said blasting bores passing through low oil bearing portions of the block having a light gauge liner disposed therein which liner also subsequently serves for passage of hot fluid through the block.

36. A method as claimed in claim 1 in which the hot fluid is a hot gas.

37. A method as claimed in claim 36 in which the hot gas is steam air, carbon dioxide or a flue gas heated externally of the mining room.

38. A process as claimed in claim 1 in which the extraction of the bitumen with the fluid and separation of said bitumen from the fluid takes place in a closed pressurized circuit.

39. A method as claimed in claim 1 which comprises driving access drifts into the rock strata above and below the oil sands body providing at least two fan shaped sets of generally upwardly extending bores emanating from the lower access drifts into the oil sands body in a pattern of contiguous parallel planes transverse to the drifts, providing said perforated pipes in those portions of the bores within the oil sands body, providing at least two fan shaped sets of generally downwardly inclined bores emanating from the overhead drifts into the oil sands body in a pattern of contiguous parallel planes transverse to the drifts and located in a position midway between the initial planes of upwardly inclined bores containing the perforated pipes thereby producing an overlapping continuous pattern of alternate planes of bores, exploding explosive charges selectively placed in the bores emanating from the upper drifts to produce a series of intercommunicating fractures between the alternate planes of bores, providing sufficient sets of these alternate planes of bores to delineate the fractured block of oil sands containing a plurality of the perforated pipes which is surrounded by the undisturbed pillar walls on all four sides, thus forming an enclosed mining room substantially capable of retaining liquids and gases under pressure, sealing the branch tunnels with bulkheads to provide a closed reservoir system capable of delivering or removing fluids through a plurality of bores without the necessity of mechanical seals, valves or piping, flooding the oil sand block or room from the upper tunnel by forcing hot fluids down through the planes of fractured bores and into the intercommunicating fractures at essentially all elevations at essentially the same time and at a temperature and for a residence time sufficient to raise the temperature of the oil sand by an amount to cause the bitumen to become flowable with the said fluid and removing the said fluid bitumen so formed, the passage of the said fluid through the said bed being via the said perforated pipes into the lower access drifts and separating the said bitumen from the said fluid.

40. A method as claimed in claim 1 which comprises driving access drifts in the underlying rock strata, providing at least two fan shaped sets of generally upwardly extending bores emanating from the first access drifts into the oil sands body in a pattern of contiguous parallel planes transverse to the drifts, providing the perforated pipes in those portions of the bores within the oil sand body, providing at least two fan shaped sets of generally upwardly extending bores emanating from the second access drifts into the oil sand body in a pattern of contiguous parallel planes transverse to the drifts and located in positions midway between the initial planes of bores containing the perforated pipes therby producing an overlapping continuous pattern of alternate planes of bores, exploding explosive charges selectively placed in the bores emanating from the second drifts to produce a series of intercommunicating fractures between the alternate planes of bores, providing sufficient sets of these alternate planes of bores to delineate a fractured block of oil sands containing a plurality of perforated pipes which is surrounded by undisturbed pillar walls on all four sides thus forming an enclosed mining room substantially capable of retaining liquids and gases under pressure, sealing the branch tunnels with bulkheads to provide a closed reservoir system capable of delivering or removing fluids through a plurality of bore holes without the necessity of mechanical seals, valves or piping, suitably flooding the oil sand block from the second access drifts by forcing hot fluids up through the planes of fractured bores and into the intercommunicating fractures at essentially all elevations at essentially the same time and at a temperature and for a residence time sufficient to raise the temperature of the oil sands by an amount to cause the bitumen to become flowable with the said fluid and removing the said fluid-bitumen so formed, the passage of the said fluid through the said bed being via the said perforated pipes into the first access drifts and separating the said bitumen from said fluid.

* * * * *

1979

United States Patent [19]

Kvapil et al.

[11] **4,153,300**

[45] **May 8, 1979**

[54] **RECOVERY OF FLUID FUELS BY IN-SITU RETORTING OF CARBONACEOUS DEPOSITS**

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[73] Assignee: **Golder Associates, Inc.**, Kirkland, Wash.

[21] Appl. No.: **908,797**

[22] Filed: **May 23, 1978**

[51] **Int. Cl.**^{2} **E21C 41/10**

[52] **U.S. Cl.** **299/2**; 299/19

[58] **Field of Search** 299/2, 19; 166/256, 166/259, 261

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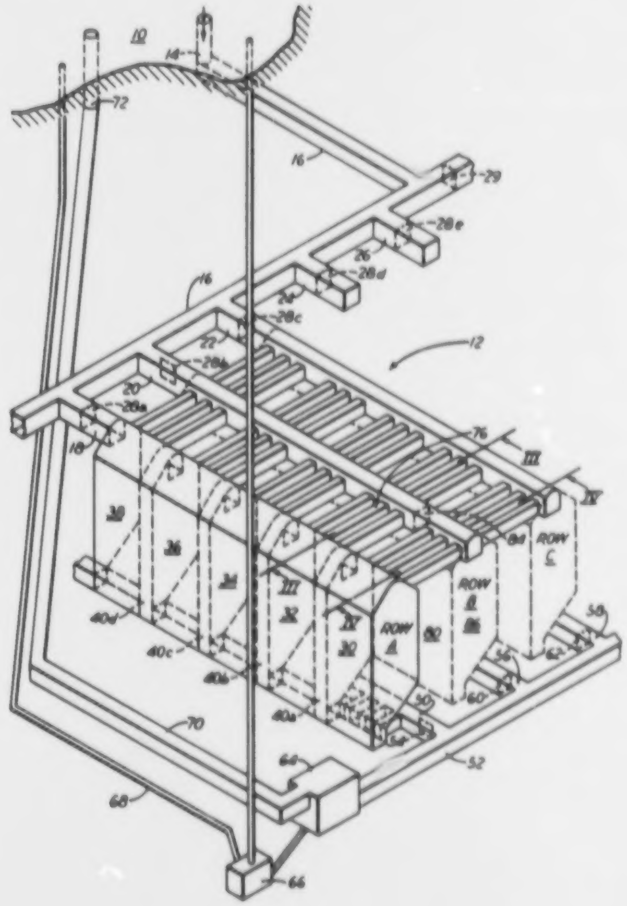
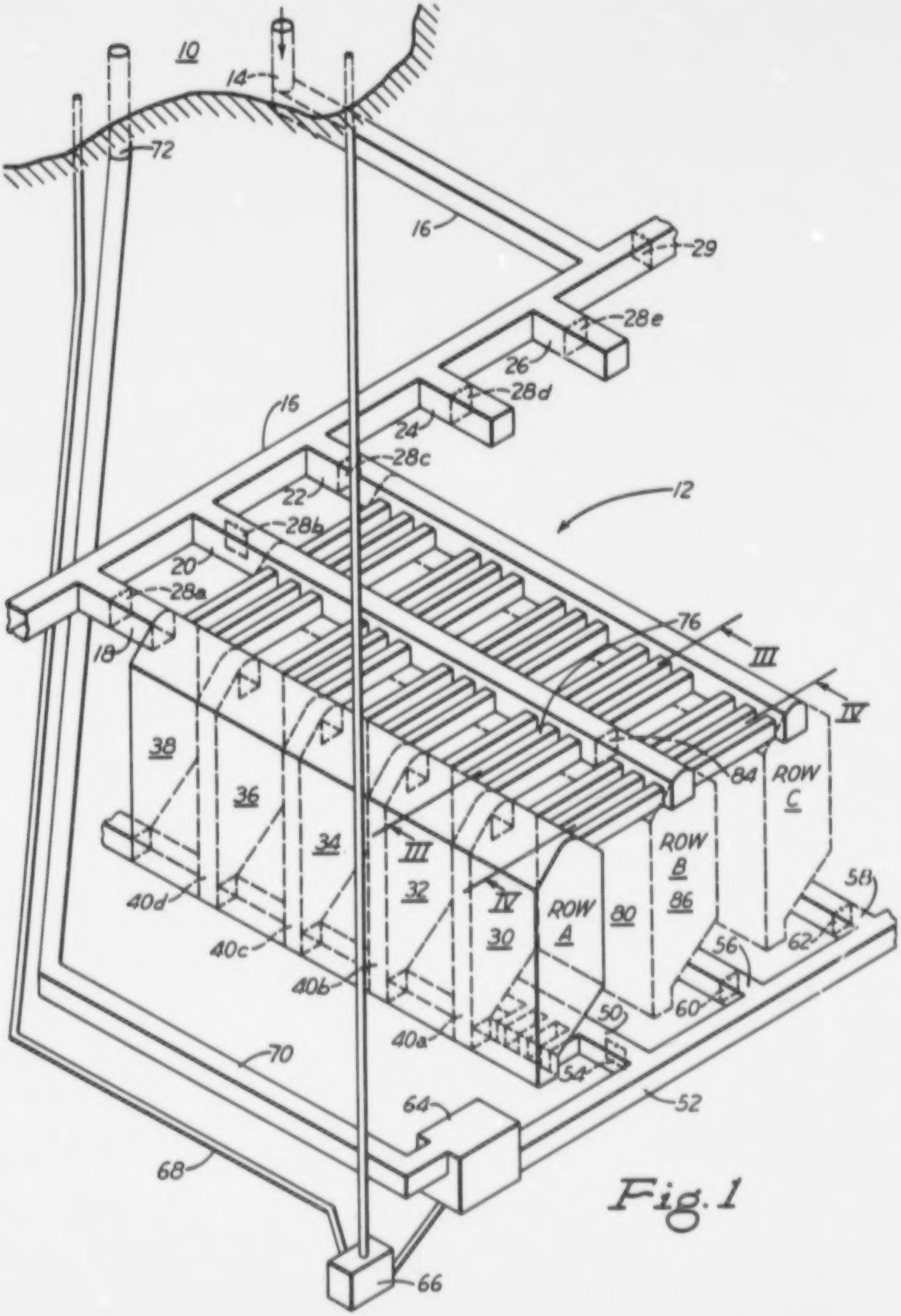
Primary Examiner—Ernest R. Purser

[57] **ABSTRACT**

In-situ retorts of elongated rectangular shape in horizontal cross section are constructed in subsurface carbonaceous deposits in a plurality of parallel rows in each of which the retorts are arranged end-to-end. The rows are separated by unbroken pillars extending upwardly from rock that is not undermined or penetrated by retorts or tunnels. The ceilings of the retorts slope upwardly at an angle of at least 40° with the horizontal to an apex or crown running longitudinally of the retorts to minimize the danger of roof collapse and provide a broadened pillar through which cross drifts opening into the crown of the retort extend for supplying combustion air. The crown of the ceiling is rounded to minimize concentration of the forces imposed by the overburden.

17 Claims, 4 Drawing Figures

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ROW C
III
IV
ROW A
ROW B

Fig. 1

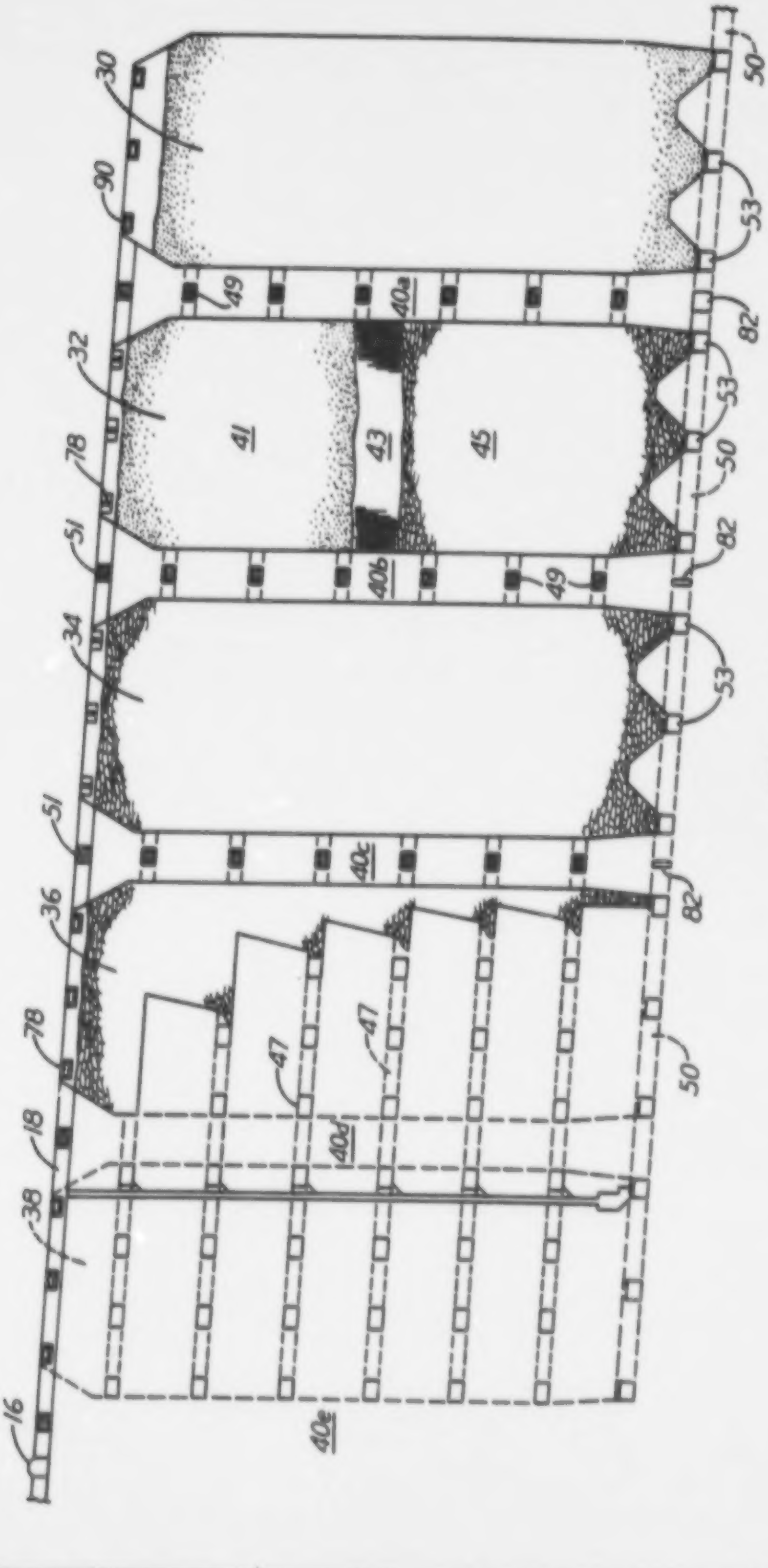

Fig. 2

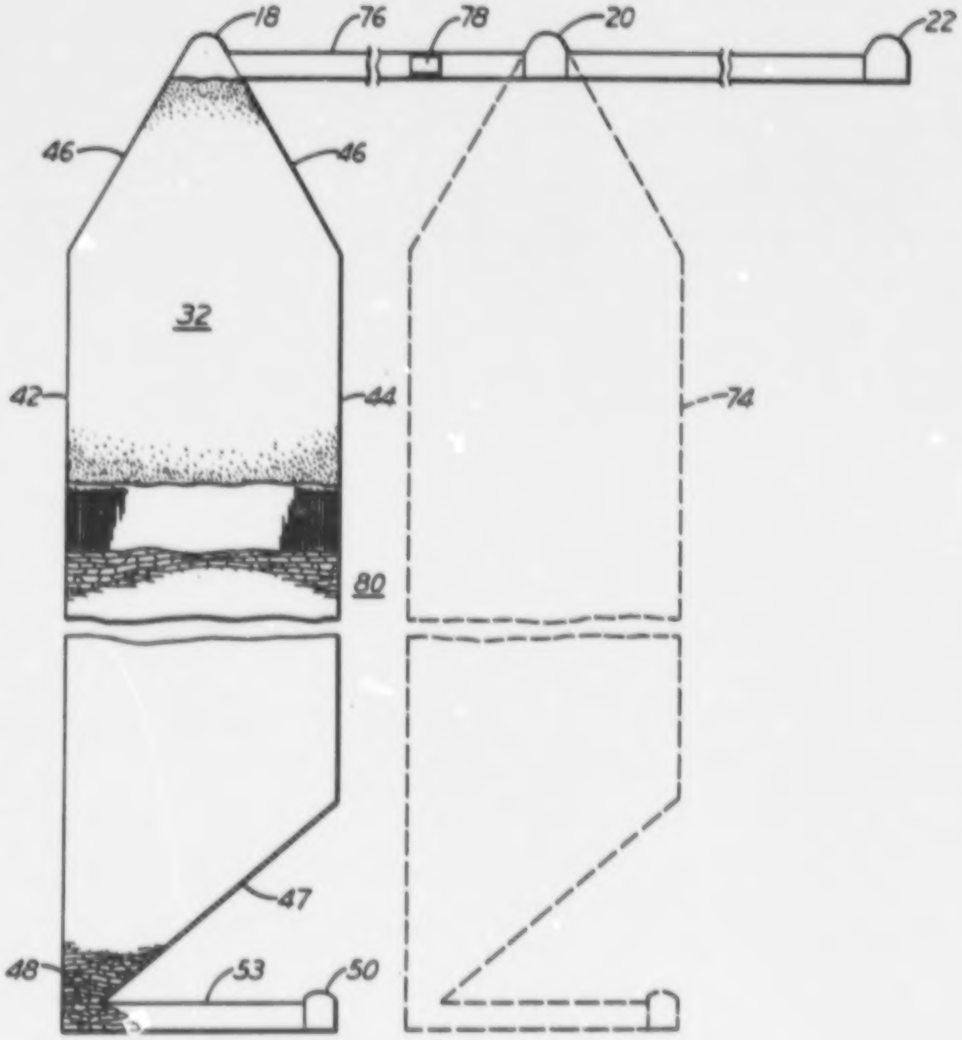
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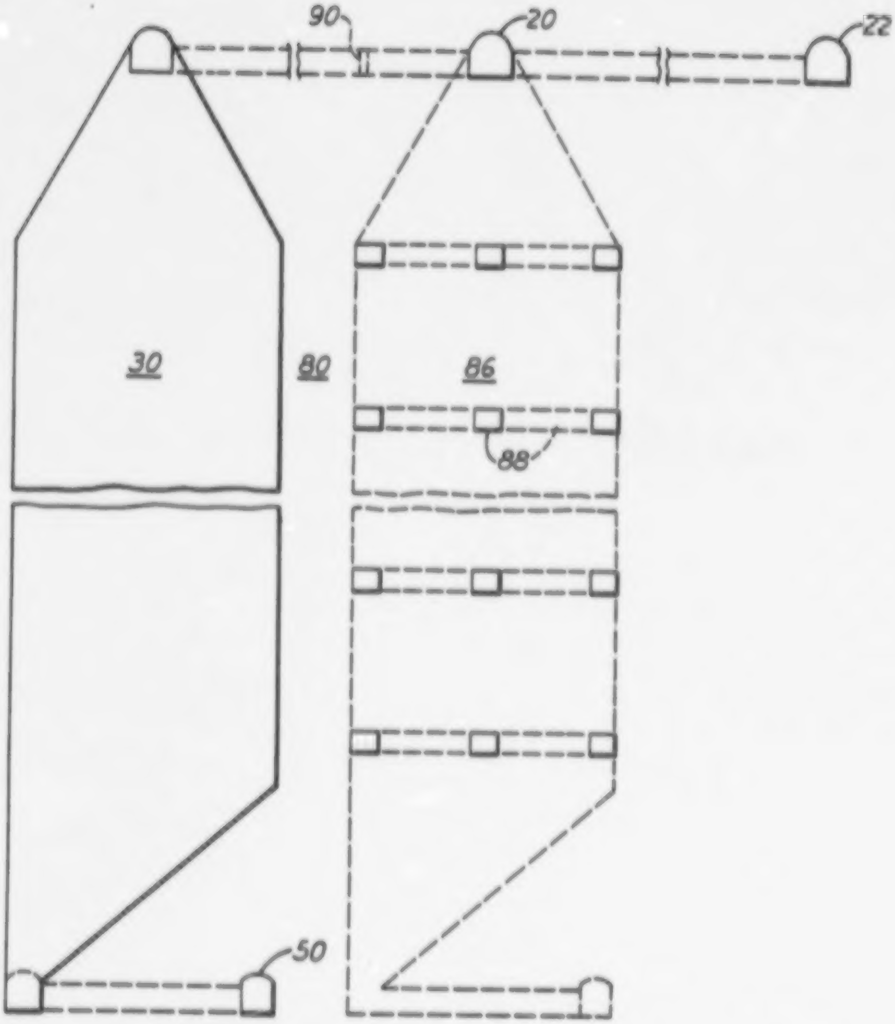
Fig. 3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86
88
50

Fig. 4

US Patent 4,099,570

Alberta OIL SANDS 007262
INFORMATION CENTRE

⑪ Ⓐ No. 1058070

(45) ISSUED 790710

(52) CLASS 166-35
C.R. CL.

(51) INT. CL. ^{2} E21B 43/24

⑲ Ⓒⓐ CANADIAN PATENT ⑫

(54) OIL PRODUCTION PROCESSES AND APPARATUS

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(21) APPLICATION No. 271,244
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(30) PRIORITY DATE U.K. (14571/76) 760409

No. OF CLAIMS 9

[illegible] BY THE PATENT OFFICE, OTTAWA
[illegible]

This invention relates to an oil recovery string for use in the recovery of oil from natural oil-bearing formations. The invention also relates to oil recovery processes.

It is known to recover oil from natural oil-bearing formations with the aid of thermal energy supplied by a fluid heating medium. United States Patent 3,386,508 describes a fluid-drive type recovery method wherein a well bore and a plurality of wells are drilled so that the wells intersect the well bore in the oil bearing formation and a hot fluid is injected into the formation from the wells to cause viscous oil to flow into and accumulate in the well bore for recovery. The number and pattern of the drilling operations which this method requires make the production costs very high. The injection of fluid into the formation from the wells must over any given period of time be confined to a limited region along the wells so as to leave lengths of the wells free to receive lowered viscosity oil. Otherwise oil recovery is limited to that which flows directly into the central well bore.

Another type of recovery system employing thermal energy is described in United States Patent 3,338,306 in which heating conduits extend along upper levels of the oil-bearing formation from a naturally exposed working surface of the formation or from a surface exposed by trenching, and heated fluid is circulated through these conduits to effect indirect heating of the oil in adjacent regions of the formation to a temperature such that the oil gravitates within the formation. As one method of recovering the heated oil the said United States Patent proposes the installation of a perforated pipe along the lower levels of the formation in a position where it will collect some of the oil as it reaches that level. In order to preserve a flow of oil through the perforations of the collecting pipe it is recommended that the pipe be installed in a drilled borehole of larger cross-section than the pipe, the reason being that the greater the space surrounding the pipe, the easier will be the collection of the gravitating oil. In order to maintain flow of oil into and along the collecting pipe this pipe is connected to pumps which pump the oil from the pipe to a surface recovery site. The preservation of a free space around the oil recovery pipe involves difficulties in practice when working unconsolidated formations such as tar sands. Therefore the oil recovery is liable to become seriously retarded in course of time. In addition it would be highly desirable to improve the economics of this type of recovery system by reducing installation costs and/or the energy consumption for a given rate of oil production.

It is an object of the invention to provide for the recovery of oil from the oil-bearing formations, in particular unconsolidated tar sands, with improved efficiency and lower installation or operating costs.

A further object is to recover oil by means of an oil-recovery pipe with distribution of heat into the formation from the vicinity of such pipe.

A more particular object of the invention is an oil recovery string of composite form combining oil-recovery and heat distribution functions.

One important discovery underlying the invention is that when employing thermal energy to cause flow of oil within an oil-bearing formation into a collecting pipe, important advantages are achieved if heat is released into the formation at the site of the collecting pipe. In particular, favourable oil recovery rates can be more quickly achieved and long term recovery rates can be improved.

By providing an oil recovery string which serves both for oil collection and for heat distribution, the present invention enables these advantages to be realized and in addition makes an important contribution to reduction of costs by reducing the number of drilling or string driving operations required.

An oil recovery string in accordance with the present invention is characterised in that it comprises a tubular casing within which there is at least one internal passageway along which heated fluid medium (liquid or gas) for supplying thermal energy to a said formation can be passed, and at least one duct along which oil can flow along the string, said casing having oil entry apertures disposed at intervals therealong, which apertures are in communication with the interior of said duct.

The invention comprehends recovery strings which are formed to effect direct and/or indirect heating of the formation. In one type of string, it serves as a heat distributor from which heated fluid medium can be injected into the oil-bearing formation. In such apparatus, the string casing has fluid discharge orifices distributed therealong and houses interior fluid pipes leading to fluid discharge orifices in different portions of the length of the string.

In another type of string, which is the preferred type, the string serves as indirect heater, the fluid heating medium being isolated from the formation. In this type of apparatus, a fluid passageway within the string casing is defined at least in part by such casing and is open only at its ends so that it can form part of a closed circuit along which heated fluid medium can be circulated in heat exchange relationship with the casing. Such apparatus permits recovery of oil in its original form, i.e., without contamination by fluid heating medium.

Direct and indirect heating are not mutually exclusive. A string can have a fluid passageway through which heated fluid medium can be circulated, within the string, in heat exchange relationship with the string casing, and may have perforations via which a proportion of the fluid medium can escape into the formation.

The oil recovery string or strings may be formed in sections which are connected using jointing techniques known per se in the formation of conventional drilling strings.

The invention includes oil recovery installations incorporating one or more oil recovery strings as herein defined, as well as oil recovery processes wherein such installations are used. Such installations and processes can be applied to formations of any type or location but are likely to be particularly advantageous for producing oil from formations with an insufficient depth of overburden to permit oil to be driven from the formation by pressure. A very important example is tar sand reservoirs which are too deep or unsuitably located for surface mining techniques, but insufficiently deep for the oil to be recovered by the known kinds of fluid injection technology wherein fluid is laterally injected into the formation from well bores. There are known large area tar sand reservoirs with an overburden of from 150 to 500 feet which could be exploited by a process according to the invention. For working relatively shallow-lying formations it will generally be preferable to employ one or more strings according to the invention wherein the fluid heating medium is kept isolated from the formation, but if fluid injection from a string or strings located at the bottom of the formation is practised, the injection can be limited so as to avoid any tendency for the injection to break down the overburden.

Depending on the geology of the oil-bearing formation and other factors, the or each oil recovery string can extend downwardly into the oil-bearing formation from the surface or from a well or a trench or other excavator working site. In certain installations according to the invention the oil recovery string or strings is or are laid at an upward inclination from an oil collecting site where there is an oil sump so that flow of oil along the string or strings and into such sump occurs by or with the assistance of gravity.

Heat additional to that which derives from the heated fluid medium fed along the oil recovery string or strings can be supplied to the oil-bearing formation at other places in any desired manner, e.g. by fluid injection or by electrical heating means.

A method of oil recovery according to the invention can be carried out in conjunction with other oil recovery techniques if so desired. For example the flow of oil into the recovery string or strings can be assisted by fire flooding or by solution gas drive if in any given case that technique is compatible with environmental considerations.

Reference is now made to the accompanying drawings in which certain embodiments of the invention, selected by way of example, are illustrated. In these drawings:

Figure 1 is a vertical section through part of an oil reservoir production plant for producing oil by a process according to the invention;

Figure 2 is a partly sectioned longitudinal elevation of part of an oil recovery string used in that process;

Figure 2a shows the construction of the string according to Figure 2, at its distal end.

Figure 3 is a transverse cross-section of the recovery string on line III-III in Figure 2:

Figure 4 is a detail of part of an installation for carrying out another process according to the invention;

Figure 5 is a cross-section of another form of oil recovery string according to the invention.

An example of a process according to the invention will firstly be described with reference to Figure 1. In this Figure, 1 is a tar or bituminous sand formation which overlies a subrock stratum 2 and is overlaid by an overburden 3 of between 150 and 500 feet in depth.

A vertical shaft 4 is driven from the surface to a level beneath the tar sand formation 1 and at the bottom of the shaft a cofferdam 5 is built. Within this cofferdam is a raised work floor 6 beneath which is an oil sump for receiving recovered oil 7. Secured to the wall of the cofferdam is a tubular guide 8 which may for example be about 10 feet in length. This guide serves to guide the direction which an oil recovery string 9 follows as the string, which is formed of successively conjoined sections, is advanced from the cofferdam. The guide is disposed so as to direct the recovery string along the bottom of the oil-bearing formation 1, supported by the subrock 2. The guide may for example have a radially inwardly projecting lug or tongue and the sections of the outer casing of the recovery string may have a receptive helical groove so that a twisting motion is imparted to the recovery string as it advances.

In suitable geological structures, rotary jet or non-rotary boring may be practised for installing the recovery string, using a jet head fed with water via a tube passing along the interior of the casing of the recovery string and that tube may subsequently remain in place and may serve some other purpose, e.g. to convey cooled heating medium back to a heat generator. If the oil bearing formation is sufficiently consolidated, it can be bored by means of an auger.

In Figure 1 only one oil recovery string is shown. There may and will normally be a plurality of such recovery strings radiating from the shaft so that oil can be simultaneously recovered from a number of different sectors around the shaft. When working a thick oil-bearing formation, one or more strings according to the invention may be provided at different levels of the formation. The jointed sections of the or each string may be of any length suitable for handling and transportation. The total installed length of each string may be as much as 500 feet or even 1000 feet or more, depending on circumstances pertaining to the geology of the formation and the available plant installation and oil receiving and storage facilities.

Steam is pumped from a steam generating plant 10 along a pipe 11 and into the casing of the recovery string 9. On reaching the distal end of the string (which end is closed), this heating medium, now relatively cool, flows back along a return tube 12 which extends along the interior of the casing, and then into an up pipe 13 leading back to the generator 10. Viscous crude in a zone of the oil-bearing formation 1 is heated by transfer from the heated string casing sufficiently to cause that oil to flow downwardly under gravity. A large proportion of this oil flows into the string and into an internal oil-receiving pipe 14. The recovery string 9 is slightly upwardly inclined to the horizontal from its source to its distal end. Consequently oil entering the pipe 14 flows therealong under gravity back to the shaft and discharges into the cofferdam sump. From this sump the oil 7 is pumped by a pump 15 along an oil delivery pipe 16 into an oil storage reservoir 17. Of course the flow of oil along the string could be achieved or assisted by a pump if required.

Due to the heating of the recovery string, oil recovery commences soon after circulation of the steam through the string is initiated. As a volume of the oil-bearing formation becomes heated by heat transfer from the string, gravitating oil tends to flow to the zone of highest temperature, i.e. to the site of the recovery string. Consequently the string receives oil from an area of the formation which is more extensive than the vertically projected area of the string. The oil recovery rate is therefore favourably high in relation to the heat energy consumed.

The construction of the recovery line 9 is shown in Figures 2, 2a and 3. It comprises a heat conducting casing 18 made of steel. Within this casing 18 there are the tube 12 which provides the return reach of the passageway along which the fluid heating medium is circulated within the string, and the oil receiving pipe 14 which have already been referred to. The steam pumped into the string from the feeder pipe 11 flows along the interior of the casing, externally of the tube 12 and the pipe 14, and at the closed distal end of the string (shown in Fig. 2a) the steam enters the open end of the return tube 12 via which the steam flows back along the string to the up pipe 13. The fluid return tube 12 has an external thermally insulating cladding 19 to prevent significant heat absorbtion from the steam which is pumped into the string casing from the steam feeder pipe 11. The oil-receiving pipe 14, has oil-entry ports 20 at intervals therealong, at least in the top portion of this pipe wall. The string casing 18 has slightly larger oil-entry ports 21 opposite the ports 20 in the oil pipe 14. Funnel portions 22 are connected to the pipe 14 to conduct oil to its oil entry ports 20 and the wider ends of such funnel portions are secured to the casing at the locations of its oil-entry ports 21 so that oil from the oil-bearing formation flows via said funnel portions into the oil-receiving pipe 14. The oil-entry ports 21 in the casing 18 are fitted with screens 23 for retaining sand particles. These screens are shaped with convexly curved upper surfaces so that retained paricles tend to be washed off the screen surfaces. In a well-consolidated formation, screens could be dispensed with. As appears from Figure 3, the oil pipe 14, which is closed at its distal end (Figure 2a) is supported by radial arms 24 secured to the casing 18. The fluid return tube 12 may be secured also to the casing, or may be secured to the oil pipe 14 so that the casing 18 and the internal tube and pipe form a unitary structure.

In a varient form of the oil recovery plant, a steam switch valve means is provided so that, at any time or times during production, some of the steam supply, can be switched to the oil pipe 14 to cause steam to discharge into the oil-bearing formation through the screens 23. This is useful for clearing the screens and boost-heating the formation.

The jointed sections of the oil recovery string may for example have a length of about 30 feet. The diameters of the casing 18, the internal fluid return tube and the oil-pipe will be selected depending on circumstances. As an example the casing may have a diameter of from 9" to 14". The diameters of the fluid return tube and oil pipe must be sufficient for the required throughput capacity of cooled heating medium and recovered oil but must leave sufficient free space within the casing for the passage of steam at a volume rate appropriate to the required heat output from the recovery line.

In a modification of the process described with reference to Figures 1 to 3, the casing 18 is provided with perforations such as perforation 18a shown in dotted line in Figure 3 to allow a proportion of the steam or other fluid heating medium to escape into the oil bearing formation.

As an example of a jointing system for the successive recovery string sections, the casing sections can be joined by welding and the lengths of the oil pipe and fluid return tube belonging to the different string sections can be formed for spigot and socket type connection, the spigot-forming end of one length having fitted sealing or packing rings which seal against the inner surfaces of the socket-forming end of the neighbouring length. This type of joint is well known to those conversant with oil recovery technology.

As an indication of the efficacy of plant as represented in Figures 1 to 3, if steam is circulated through the or each oil recovery string at a temperature and flow rate corresponding to a heat input of between 500 and 1000 BTU/hr per square foot of the string casing surface then, depending on the composition of the oil reservoir, the temperature of the oil-bearing sand at regions from 6 to 10 feet from the string can be raised sufficiently to induce oil flow from such regions within a period of one year. However the energy input can be substantially outside this range. The optimum values of the various parameters such as heat input rate, number of strings etc. can be determined from pilot projects and calculations for a given location.

It is not essential to provide a working shaft such as 4 in Figure 1. One or more small diameter wells may be drilled which communicate with the recovery string(s) and which is or are associated with means whereby the circulation of steam or other heating fluid through such string(s) can take place via such well(s). Oil can be pumped to the surface via one or more such wells from a different location. For example a pattern of vertical wells, mutually spaced e.g. by 40 to 60 feet from each other could be linked by a system of recovery strings according to the invention each extending from one well to another.

Figure 4 shows part of another oil-recovery string according to the invention. This recovery line 25, extends along the bottom or lower region of an oil-bearing formation from a shaft 26 fitted with a line guide 27 similar to guide 8 in Figure 1. In the Figure 4 embodiment the recovery string comprises a tubular casing 28 which is internally divided by partitions 29 into successive compartments. Vertical steam pipes 30 extend from a steam generator at the surface down to an oil sump at the bottom of the shaft and branch pipes such as 31 extend from these vertical pipes to the different interior compartments of the casing 28. The vertical steam pipes are fitted with valves such as 32 for controlling steam flow. In each portion of its length corresponding with one of the said interior compartments the casing 28 has at least one peripheral port such as 33 opening upwardly into the oil-bearing formation. The said ports are if necessary fitted with sand screens.

Steam under pressure is injected via the branch pipes into the internal compartments of the casing 28 so as to discharge upwardly from these compartments through the sand screens. The pumping of steam from each compartment occurs intermittently. For example, steam may be pumped from any given compartment or any given group of compartments for a period of one or more days or even a week or more, to be followed by pumping of steam from another compartment or group of compartments. When steam delivery to certain compartments is terminated, the corresponding valves 32 are opened. Oil which has been heated during the steam delivery from such compartments can now drain into such compartments via the screened ports 33. Once such compartments contain liquid up to a certain level, oil entering the compartments commences to discharge via the associated pipes 31 into the connected vertical pipes 30 along which the oil drains to the sump.

To permit such discharge of oil, the conduit 28 is laid at a slight upward inclination from the shaft. Alternatively oil entering the compartments of the conduit can be drawn off by pumps.

By virtue of the division of the string casing into compartments, which compartments or groups of which compartments are associated with independent supply pipes for heated fluid a favourable heat distribution along the string can be ensured. If steam is merely fed into a perforated pipe the steam tends to escape via the shortest route and the heat distribution in the formation would be poor.

Figure 5 shows a further form of oil recovery string. The string sections each comprise a casing 35 having oil-entry ports 36. Within the casing there is an oil-receiving pipe 37 having oil-entry ports 38 and the casing 35 and pipe 37 are secured together, e.g. by welding, so that the ports 36 and 38 are in sealed communication. Steam or other heated fluid medium can be supplied along the string between the oil-receiving pipe 37 and the casing so as to heat the casing and the oil-receiving pipe. The string can for example be installed between two shafts with flow of the heating medium from one shaft to the other. If required a tube 39 may be provided within the casing so that return flow of heating medium can take place within the string, through this tube.

An oil recovery string according to my invention could be used in processes other than those hereinbefore described. For example, such a string, preferably fitted with screening means for retaining solid particles above a certain size, can be used in oil recovery by installing the string depthwise of the oil-bearing formation, e.g. as part of a drilling pipe or string driven down to the formation from the surface. It may be possible to dispense with a shaft. A plurality of such strings could be driven at a given production point. Depending on the form of the string, heating may take place by injection of hot fluid medium from the string and/or by internal circulation of steam or other hot fluid medium within the string.

Having thus described the invention it will be understood that such description has been given by way of illustration and not by way of limitation. Numerous modifications, additions and subtractions may be made to the illustrated embodiments without departing from the spirit or scope of the invention.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An oil recovery string for use in recovering oil from a natural oil-bearing formation with the aid of thermal energy supplied by a fluid heating medium, said string comprising a tubular heat-conducting casing having oil entry apertures disposed at intervals therealong, an oil-receiving pipe located within said casing and having peripheral openings in sealed communication with said oil-receiving apertures in the casing, and wherein between said casing and said oil-receiving pipe there is a passageway along which heated fluid medium can be circulated in heat-exchange relationship with the casing.

2. An oil-recovery string according to Claim 1, wherein the string is formed so that the whole or substantially the whole of the interior surface of said casing is exposed to heated fluid when this is circulated along said passageway.

3. An oil recovery string according to Claims 1 or 2, wherein said oil-receiving pipe is disposed so that its axis is substantially centrally located within the cross-section of said casing, wherein there is a tube extending along said string, between said oil-receiving pipe and the casing, and wherein the interior of said tube and the free space which is external to said tube and is between the oil-receiving pipe and the casing constitute reaches of a said passageway along which heated fluid medium can be circulated within the string.

4. A process for recovery of oil from a natural oil-bearing formation utilizing thermal energy supplied by a fluid heating medium to cause or accelerate flow of oil from the formation into an oil recovery duct, with the improvement that in a direction along the formation there is installed at least one composite heating and oil recovery string having a heat conducting casing within which there is at least one passageway for conducting fluid heat-

ing medium along the string in heat exchange relationship with such casing, and within which casing there is also at least one duct for conducting oil along the string, the said casing having peripheral oil entry apertures at intervals therealong which apertures are in sealed communication with said oil-receiving duct located within said casing, and fluid heating medium is forced along said heating passageway to heat a volume of the oil-bearing formation by heat transfer from the string so that oil is caused to gravitate from the formation into said oil-receiving duct via said oil entry apertures.

5. A process according to Claim 4, wherein within said casing there is also a return tube for the fluid heating medium and the fluid heating medium is forced along said passageway in contact with said casing, from one end of said string to the other end thereof, at which other end said fluid heating medium enters said return tube and then flows along that tube back to said one end of the string.

6. A process according to Claim 4, wherein the opposed end of said casing are connected into a closed circuit along which the fluid heating medium is circulated.

7. An oil recovery string for use in recovering oil from a natural oil-bearing formation with the said of thermal energy supplied by a fluid heating medium, said string comprising a tubular casing adapted to be laid in a direction along an oil-bearing formation, said casing having ports at intervals therealong via which oil gravitating from regions of the formation above the string can enter said casing, and having partitioning means subdividing the interior of the casing into different compartments distributed along the casing, and a plurality of fluid conducting pipes which extend along the interior of said casing

and have fluid discharge ends thereof disposed in different said compartments to permit heating fluid to be intermittently discharged from ports in different portions of the length of the casing, for heating oil in said regions of the formation, by forcing such medium intermittently through said pipes.

8. A process for recovery of oil from a natural oil-bearing formation utilizing thermal energy supplied by a fluid heating medium to cause or accelerate flow of oil from the formation into an oil recovery duct, with the improvement that in a direction along the formation there is installed at least one composite heating and oil recovery string comprising a tubular casing having ports at intervals therealong via which the interior of the casing is in communication with the formation, and comprising a plurality of fluid conducting pipes which extend along the interior of said casing and are in communication with ports in different portions of the length of the string, and at intervals of time fluid heating medium is forced along said pipes and into said formation via said ports to heat a volume of the oil-bearing formation so that oil is caused to gravitate from the formation into said oil-receiving duct via said ports.

9. A process according to Claim 4 or 8, wherein said string extends along the formation at an inclination so that oil entering said oil-receiving duct flows therealong under gravity.

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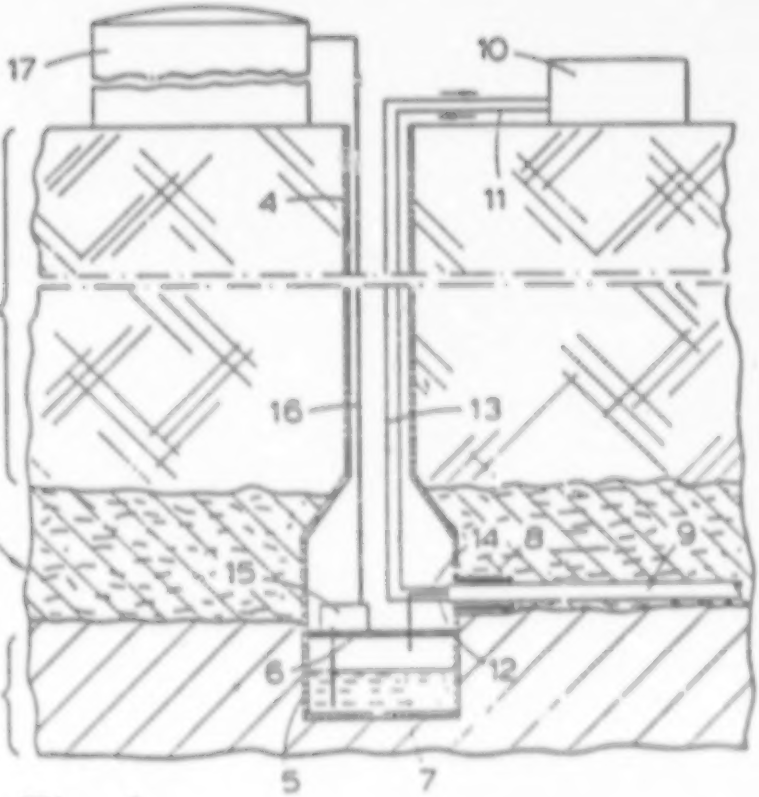
3-1


17
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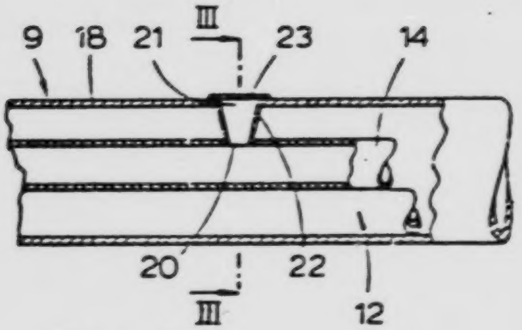
8
9
6
12
2
5
7

Fig.1

1055070
3·2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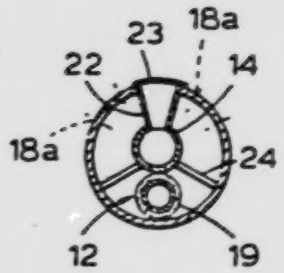
22
12
III

Fig. 2


23
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19

Fig.3

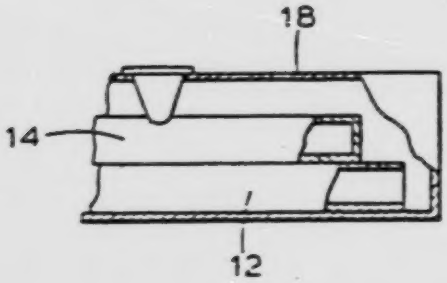
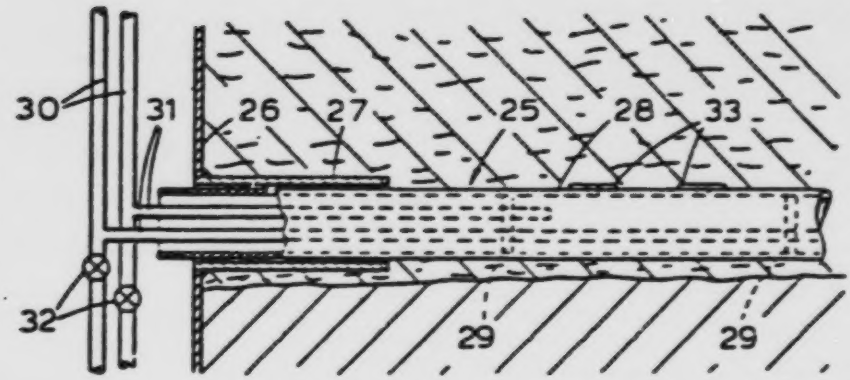


Fig. 2a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31
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25
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33
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29
29

Fig.4

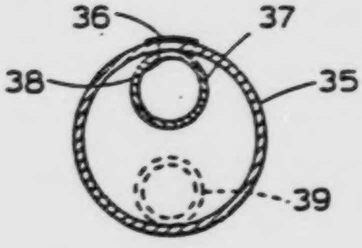

36
37
38
35
39

Fig. 5

00/ 34

INFORMATION CENTRE

United States Patent [19]

Kvapil et al.

[11] **4,162,808**

[45] **Jul. 31, 1979**

[54] **IN-SITU RETORTING OF CARBONACEOUS DEPOSITS**

[75] Inventors: **Rudolph Kvapil**, Denver; **K. Malcolm Clews**, Littleton, both of Colo.

[73] Assignees: **Gulf Oil Corporation**, Pittsburgh, Pa.; **Standard Oil Company (Indiana)**, Chicago, Ill.

[21] Appl. No.: **908,798**

[22] Filed: **May 23, 1978**

[51] **Int. Cl.²** **E21C 41/12**

[52] **U.S. Cl.** **299/2; 166/259**

[58] **Field of Search** 299/2; 166/259; 175/12

[56] **References Cited**

U.S. PATENT DOCUMENTS

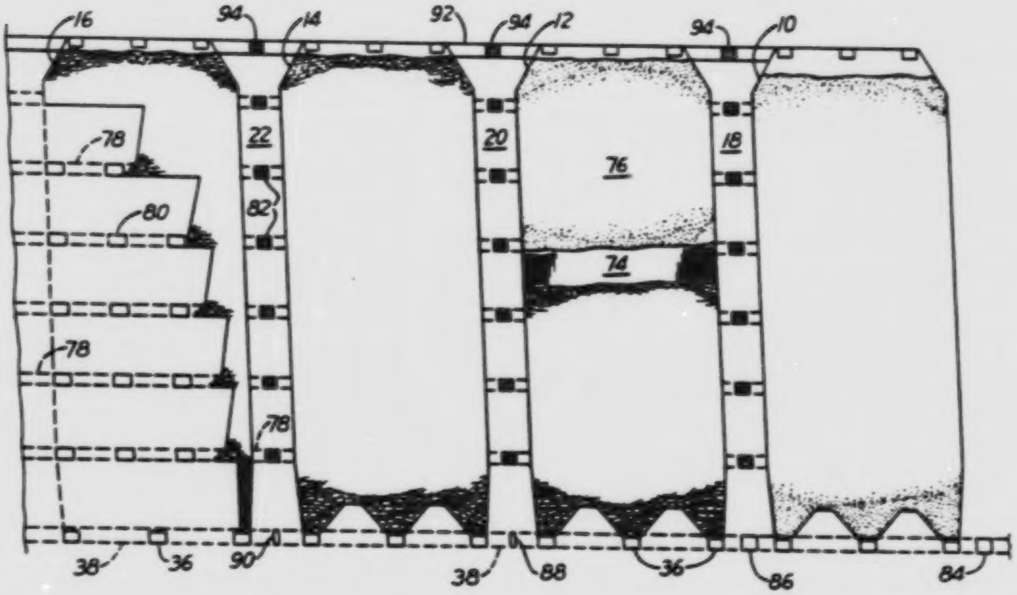
3,349,848	10/1967	Burgh	166/259
3,917,344	11/1975	Janssen et al.	299/2
3,950,029	4/1976	Timmins	299/2

Primary Examiner—Ernest R. Purser

[57] **ABSTRACT**

A method of producing fluid fuels from carbonaceous deposits such as oil shale, heavy oils and coal by in-situ retorting of the carbonaceous deposit in rubblized in-situ retorts utilizes a plurality of such retorts. The retorts are subjected to a sequence of preparation for rubblization, rubblization and combustion of carbonaceous material to supply heat to produce a fluid fuel from kerogen in the carbonaceous deposit. At least one completely rubblized retort is maintained throughout its entire volume under the inlet pressure of the combustion air between retorts in which rubblization or stopping is taking place and retorts in which the combustion of the carbonaceous deposit is proceeding to prevent flow of toxic gases from the retort in which combustion is proceeding to a retort in which preparation for rubblization and rubblization are occurring. The invention is described in detail for the recovery of shale oil from oil shale deposits.

13 Claims, 3 Drawings



UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 4,162,808 Dated July 31, 1979

Inventor(s) Rudolph Kvapil and K. Malcolm Clews

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Abstract, line 11, "stopping" should be --stoping--.

Column 8, line 10, "2" should be --10--.

Column 6, lines 12, 13, and 15, "rubberized" should be --rubblized--.

Signed and Sealed this

Twenty-third **Day of** *October 1979*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

LUTRELLE F. PARKER
Acting Commissioner of Patents and Trademarks

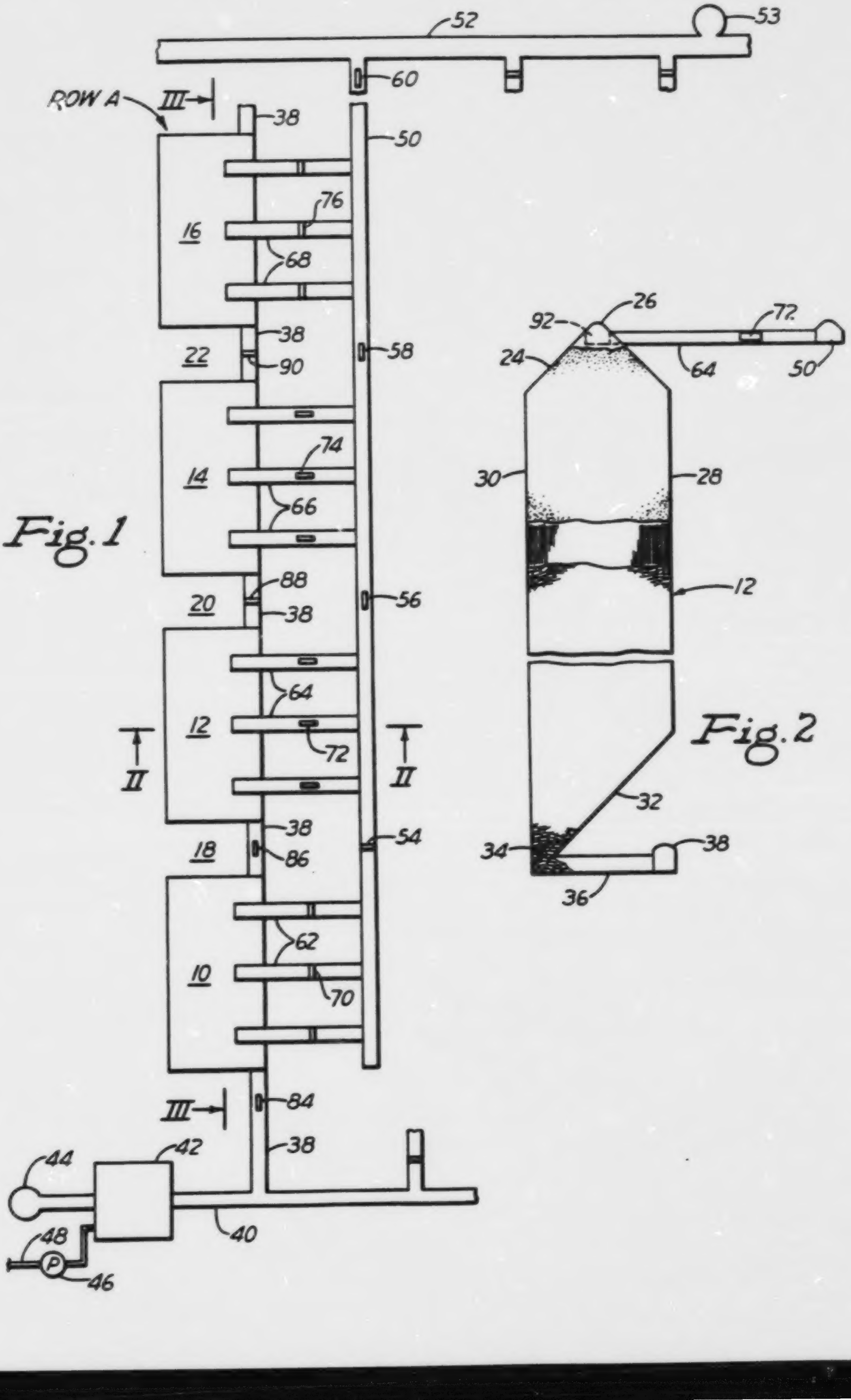

ROW A
III
II
II
III
P

Fig. 1

Fig. 2

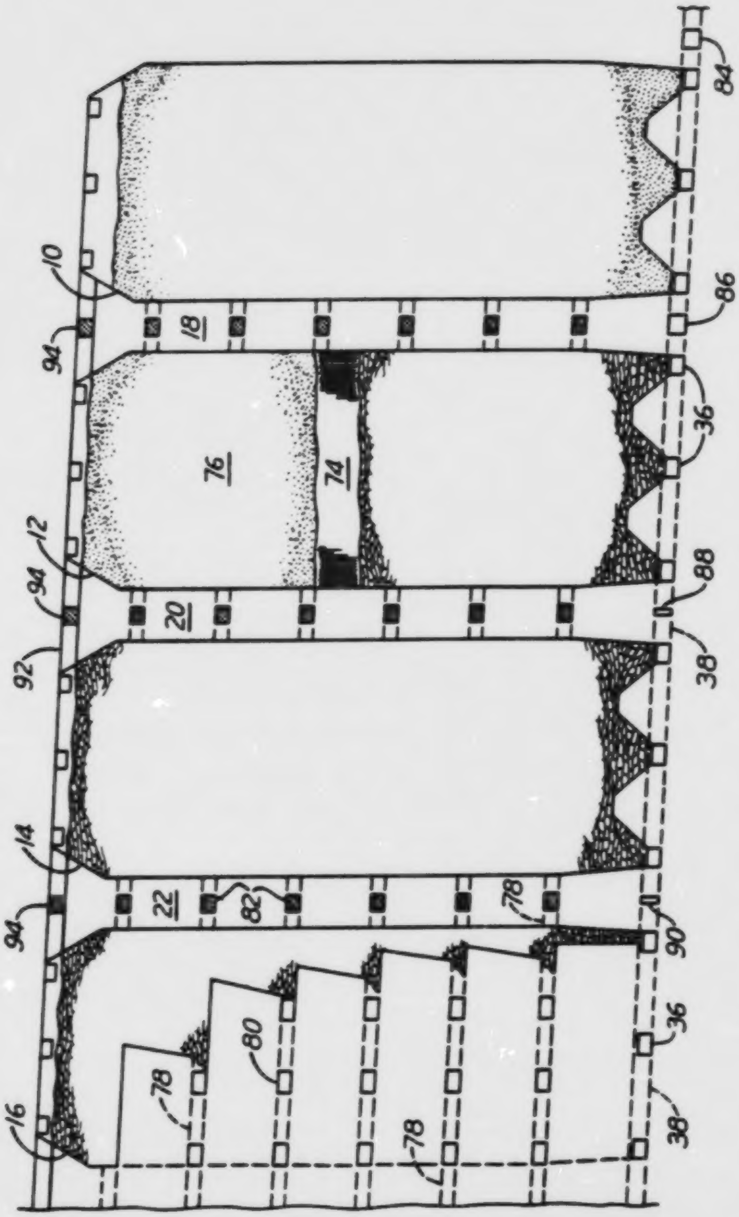


Fig. 3

IN-SITU RETORTING OF CARBONACEOUS DEPOSITS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the in-situ retorting of carbonaceous deposits to produce fluid fuels, and more particularly to an improved method of producing such fuels in which danger of exposing workers to toxic gases is minimized.

2. Description of the Prior Art

Immense potential sources of carbon-containing compounds suitable as fluid fuels exist in subsurface carbonaceous deposits of oil shale, coal, and heavy, highly viscous petroleum oils. The highly viscous petroleum oil deposits are frequently referred to as tar sands. Because the carbonaceous material in the deposits is either solid as in oil shale and coal or highly viscous as in tar sands, treatment of the carbonaceous deposit to make the carbon-containing compounds fluid is necessary to deliver them from the deposit to the surface. A method of treatment that has been used is to heat the deposit to a temperature at which fluid carbon-containing compounds are formed or the viscosity of heavy oils is drastically reduced. One method of heating the deposit is by in-situ combustion in which a portion of the carboniferous material in the deposit is burned in place by igniting the deposit and injecting air into the deposit to heat oil shale or tar sands to a temperature at which oils of low viscosity are produced or to produce combustible gaseous products from coal.

The very low permeability of oil shale to the flow of fluids makes it necessary to rubblize the shale to form an in-situ retort through which fluids for heating the shale to a temperature high enough to convert the kerogen to shale oil can be circulated. While sometimes coal and tar sands may be sufficiently permeable for an in-situ combustion process, rubblization of those deposits can be advantageous in reducing channeling through the deposits. One of the methods of forming an in-situ retort is described in U.S. Pat. No. 1,919,636 of Karrick. In the process described in that patent, a vertical central shaft is driven through the oil shale to provide the desired void space necessary for permeability and the oil shale is blasted from the walls of the shaft to fill the shaft with broken oil shale. Other mining procedures for forming a rubblized in-situ retort are described in U.S. Pat. Nos. 2,481,051 of Uren, 3,001,776 of Van Poollen and 3,661,423 of Garrett. Those patents suggest using various mining techniques such as sublevel stoping, sublevel caving, block caving and shrinkage stoping to form the in-situ retort.

It is necessary during the in-situ retorting of oil shale to introduce the combustion air into the retort at a pressure substantially above atmospheric pressure to force the air through the retort at a rate high enough to maintain combustion of oil shale in the retort. The large volume of gases that must pass through the retort and the height of the retort cause a substantial pressure drop in the gases as they travel from the combustion air inlet preferably at the top of the retort to the outlet of the retort at its lower end. If it were attempted to maintain subatmospheric pressure in retorts during the burning of oil shale, the volume of the gases drawn from the retort would be excessive.

It is likely that there will be fractures in the oil shale formation that extend outwardly from rubblized retorts. The fractures will in many instances be naturally occurring fractures in the formation that existed before the retort was constructed but may also be fractures formed during the rubblization. Since retorts are maintained at substantially atmospheric pressure while being prepared for rubblization and during the rubblization, there is danger of flow of gases from a retort that is in the process of retorting oil shale to retorts that are being prepared for rubblization or are in the process of being rubblized. Gases developed during the retorting are highly toxic and may develop explosive mixtures when mixed with air.

SUMMARY OF THE INVENTION

This invention resides in a method of producing fluid fuels by in-situ retorting of carbonaceous deposits in rubblized subsurface retorts in which a row of retorts is formed and the carbonaceous deposit is ignited successively in the retorts beginning in the retort at one end of the row and progressing toward the other end of the row. At least one completely rubblized retort exists at all times between a retort in which combustion is occurring and a retort in which rubblization or preparation of a retort for rubblization is occurring. The intervening rubblized retort is maintained at a pressure at least as high as the pressure at the inlet end of retorts in which combustion is proceeding.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic plan view of a portion of an array of retorts in a subsurface oil shale deposit.

FIG. 2 is a transverse vertical sectional view taken along section line II—II in FIG. 1.

FIG. 3 is a longitudinal vertical sectional view taken along section line III—III in FIG. 1.

DESCRIPTION OF PREFERRED EMBODIMENT

For purposes of illustration, a preferred embodiment of this invention is described for the recovery of shale oil from oil shale deposits.

Referring to FIG. 1 of the drawings, a plurality of retorts 10, 12, 14 and 16 in a subsurface oil shale deposit are arranged in a row designated as row A. The retorts shown are of rectangular shape and horizontal cross section and are arranged end to end with the adjacent retorts separated by end pillars 18, 20 and 22. While only four retorts have been shown in row A in FIG. 1 to simplify the drawings, it is contemplated that a row of retorts will include more than four retorts, four retorts being adequate for a description of this invention.

As is shown in FIG. 2, the retorts may have a height that substantially exceeds their lateral dimensions. The height will depend upon the thickness of the shale deposits in which the retorts are constructed. In a typical installation in the shale deposits in Rio Blanco County, Colo., the retorts may have a width of 100 to 150 feet, a length of 100 to 300 feet, and a height of 400 to 750 feet. The end pillars will have a thickness in the range of 60 to 125 feet. The dimensions given are merely typical of a suitable retort design in a particular formation. This invention is not restricted to use in retorts of rectangular cross section or to retorts having any particular ratio of height to width or length.

Again referring to FIG. 2, a preferred retort structure is shown in which the ceiling 24 of the retort slopes downwardly from a peak 26 at an angle preferably in the range of 40° to 55° to intersect sidewalls 28 and 30 at their upper ends. Sidewall 30 extends substantially vertically downward to the lower end of the retort. Sidewall 28 intersects at its lower end the upper end of a sloping bottom 32 of the retort. Bottom 32 slopes at an angle of 40° to 50° from sidewall 28 to an outlet 34 adjacent sidewall 30 that extends longitudinally along the bottom of the retort for its full length. A plurality of product drifts 36 extend transversely from the outlet 34 below the bottom 32 of the retort and intersect an exhaust tunnel 38.

Referring to FIG. 1, exhaust tunnel 38 extends for the full length of the row of retorts. It extends beyond retort 10 to open into a collection tunnel 40 for the delivery of products into a separator 42 in which gaseous products are separated from liquid products. It is preferred that tunnel 38 extend downdip, as shown in FIG. 3, at a slope of 3° to 10° to facilitate flow of liquid products to the collection tunnel. Separator 42 is connected with a shaft 44 for delivery of gaseous products to the surface. For a retort of the size described above, shaft 44 preferably has a cross-sectional area of about 400 sq. ft. An exhaust fan may be installed in shaft 44 to reduce the pressure at the outlet of the retorts during the retorting phase. Liquid products from separator 42 are pumped by pump 46 through a line 48 to the surface.

Running parallel to the retorts in row A at the elevation of the top of the retorts is an apex drift 50. Apex drift 50 is connected to a combustion air tunnel 52 which in turn is connected with a combustion air shaft 53 for delivery of compressed air from compressors, not shown, at the ground surface. Installed in the apex drift 50 in alignment with the pillars 18, 20, etc. are remote-controlled combustion air control doors 54, 56 and 58. There is also a remote-controlled air control door 60 adjacent the intersection of apex drift 50 and combustion air tunnel 52. A plurality of cross drifts extend from the apex drift 50 to each of the retorts in row A. Cross drifts open into the retorts just below the crown 26 as is best illustrated in FIG. 2. The cross drifts opening into retort 10 are indicated by reference numeral 62, into retort 12 by reference numeral 64, into retort 14 by reference numeral 66, and into retort 16 by reference numeral 68. Remote-controlled combustion air control doors are installed in each of the cross drifts. The combustion air control doors in cross drifts 62 are indicated by reference numeral 70, in cross drifts 64 by reference numeral 72, in cross drifts 66 by reference numeral 74, and in cross drifts 68 by reference numeral 76.

The retorts are subjected to the sequence of preparation for rubblizing, rubblizing and retorting steps, as is best illustrated in FIG. 3 of the drawings. Rubblization of the retorts can be accomplished by any desirable technique such as those described in the Karrick, Van Poollen and Uren patents. A preferred method is sublevel caving such as is shown in retort 16 in FIG. 3. Withdrawal drifts 78 and mining drifts 80 are driven in the retorts for use in the sublevel caving operation. Withdrawal drifts 78 extend through the end pillars but are sealed as indicated by reference numeral 82 in FIG. 3 after rubblization is completed. The desired permeability is obtained by withdrawing 10 to 30 percent of the shale to provide void space for the rubblization.

The final step in the sequence of operations in the retorts is the retorting of the oil shale. Retorting is preferably accomplished by the burning of a fuel in the upper end of the retorts to heat oil shale in that portion of the retort to a temperature at which ignition occurs. Injection of combustion air into the upper end of the retort is continued after ignition to cause carbonaceous residue on the oil shale to burn and form hot combustion products. The hot combustion products travel downwardly ahead of the combustion zone to convert kerogen in the oil shale below the combustion zone to shale oil which drains from the bottom of the retorts. Conversion of kerogen to shale oil leaves a carbonaceous deposit on the shale. The carbonaceous deposit serves as the fuel that is burned in the combustion zone. As combustion proceeds, the combustion zone travels downwardly through the retorts until retorting is complete.

Referring to FIG. 3, retort 10 is shown after combustion has been completed in that retort. Retort 12 is shown as combustion is occurring in the retort with the combustion zone 74 underlying a spent shale zone 76. Below the combustion zone is rubblized shale which will be virtually devoid of shale oil immediately below the combustion zone 74 and may be practically raw shale at the bottom of the retort. Retort 14 is completely rubblized and retort 16 is in the process of being rubblized. In the exhaust tunnel 38 between retort 10 and the collection tunnel 40 is a door 84 that is open to allow products from the retort to flow to the collection tunnel. A similar door 86, also open, in exhaust tunnel 38 allows flow from retort 12 to the collection tunnel, and a door 88 in exhaust tunnel 38 between retorts 14 and 12 is closed to isolate the rubblized retort 14 from retort 12. A door 90 in exhaust tunnel 38 between retort 14 and retort 16 isolates retort 14 from retort 16 in which rubblization is taking place. All of doors 84, 86, 88 and 90 are remote controlled. They could be replaced by a pair of remote controlled doors spaced apart the length of a retort that could be moved in the exhaust tunnel updip to isolate a rubblized retort from the adjacent downdip retort being retorted and updip retort being rubblized as combustion progresses through the retorts in row A from retort 10 to retort 16. Seals 82 in the withdrawal drifts 78 prevent flow from the rubblized retort 14 to adjacent retorts through the withdrawal drifts. The mining drifts 80 do not extend beyond the sides of the retorts.

It is preferred that an apex drift 92, similar to apex drift 50, extend longitudinally of row A and form the crown of the retorts in the row to improve the control of the shape of the upper end of the retort and facilitate the mining operations. The apex drift 92 is sealed at 94 where it extends through the end pillars separating the retorts upon completion of the rubblization of the retorts. Thus, as shown in FIG. 3, apex drift 92 has not been sealed at the updip or left-hand end of retort 16.

Upon completion of the retorting in retort 10, rubblization of retort 14 will have been completed. Door 54 in apex drift 50 will be closed as will doors 70 in cross drifts 62 to prevent further flow of combustion air into retort 10. Doors 74 in cross drifts 66 are opened to allow flow of combustion air into retort 14 to raise the pressure in the retort to the pressure at which combustion air is supplied through apex drift 50. Doors 88 and 90 in the exhaust tunnel 38 are closed to isolate retort 14 and prevent flow of combustion air out of the retort; thereby maintaining the entire volume of the retort at the pressure of combustion air where cross drifts 66 open into apex drift 50. Doors 72 in cross drifts 64 are open and doors 84 and 86 in the exhaust tunnel 38 are open to allow flow through retort 12. Shale in retort 12 is ignited, for example by burning a fuel in the upper end of the retort while supplying combustion air to heat the shale to a temperature at which combustion will proceed. The supply of combustion air to the retort is continued to cause the combustion front in the retort to move downwardly through the retort and convert kerogen in the shale below the combustion front to shale oil. The position of doors 72 is adjusted to control the total flow of air and its distribution to maintain a desired rate of progress of the combustion front that is uniform over the length of the retorts.

In the preferred embodiment of the invention illustrated, combustion air is supplied to the rubblized retort from apex drift 50 at a location that is upstream from the point at which combustion air is supplied to the retort 12; therefore, the isolated rubblized retort is at a pressure that will exceed slightly the pressure at the upper end of the retort in which combustion occurs. Moreover, the flow through the retort in which combustion is occurring causes a pressure drop in that retort; hence, the pressure in the rubblized retort 14 will exceed the pressure in the retort 12 a greater amount at the lower end of the retort below the combustion front where the gases in the retort 12 are most toxic.

By the time retorting is completed in retort 12, retort 16 will be completely rubblized; then at the time of ignition of shale in retort 14, retort 16 will be isolated and subjected to the pressure of the combustion air in the manner just described for retort 14. Similarly, retort 12 was isolated and maintained at the combustion air supply pressure while combustion proceeded in retort 10. Since the row will ordinarily contain more retorts than the four illustrated, the procedure is repeated progressively updip towards the combustion tunnel 52. Scheduling of the rubblizing and retorting operations may be such that retorting proceeds in more than one retort at any given time. Regardless of the number of retorts in which combustion is taking place, at least one isolated completely rubblized retort is maintained at the increased pressure between a retort in which combustion is taking place and a retort in which rubblization or stoping operations are underway.

This invention has been described for the rubblization and retorting of oil shale in a single row of retorts in an array. Ordinarily, there will be a large number of rows of retorts in an array. For example, retorts will be constructed under apex drift 50. Following the operations in row A, the doors 54, 56 and 58 can be successively closed to allow future retorts downstream of the closed valves to be isolated from the combustion air and permit rubblization operations to proceed in retorts downdip of the closed doors. The temperature of the combustion air resulting from its compression to a pressure which may be 25–40 psia will preclude mining in areas exposed to that air. By moving progressively upstream, rubblization can proceed in the adjacent row, but at no time will stoping or rubblization proceed in a retort under apex drift 50 directly opposite a retort in row A in which combustion is proceeding.

This invention maintains at least one completely rubblized retort at the pressure of the inlet pressure of combustion air to retorts between retorts in which mining activities for rubblizing shale in a retort are occurring and retorts in which combustion of shale is taking place. When combustion air is injected into the top of a retort and burning progresses downwardly through a retort, the pressure at the top of the retort in which burning occurs is only slightly less than the pressure in the rubblized retort. Because of the pressure drop inherent to flow through a rubblized zone, the pressure below the combustion zone in the retort in which burning is occurring is lower than the pressure in the rubblized retort in which there is no combustion; consequently, flow is in the direction from the rubblized retort to the burning retort. In the preferred embodiment of the invention, the retorts are arranged in parallel rows and combustion air is supplied to retorts in one row from a drift that will subsequently be incorporated in retorts in an adjacent row, and combustion in the retorts progresses in a direction opposite to the direction of the flow of combustion air through the apex drift. After completion of burning in a retort that portion of the apex drift directly opposite the completely burned retort is blocked to flow of the combustion air and rubblization proceeds under the blocked portion of the apex drift. In this manner, rubblization can proceed in the adjacent row only after retorting is completed in a directly opposite retort.

While this invention has been described with specific reference to the production of shale oil from oil shale deposits, it is also useful in the production of heavy, highly viscous petroleum from petroleum reservoirs such as tar sands of low permeability where an increase in permeability as well as reduction in the viscosity of the oil is desirable for production at acceptable rates. The procedure can also be used for the in-situ gasification of coal in rubblized retorts in coal beds, and particularly in rubblized retorts in thick coal beds such as are found in some of the western states. The term "carbonaceous deposits" is used in this specification and the claims to designate oil shale, coal and petroleum reservoirs such as tar sands containing heavy oils of high viscosity.

We claim:

1. A method of producing fluid fuels by combustion of combustible material in carbonaceous deposits in in-situ retorts comprising successively constructing in a subsurface carbonaceous deposit in-situ retorts in a row by the sequence of stoping the retorts for rubblization and rubblizing the carbonaceous material in the retorts, each of the retorts having an inlet and an outlet spaced from the inlet, successively igniting the carbonaceous deposit in each of the retorts in series beginning at the retort at one end of the row and finishing at the retort at the opposite end of the row, injecting combustion air into the inlet of a first retort in which the carbonaceous deposit has been ignited to cause a combustion front to move through the retorts toward the outlet and release a fluid fuel from the carbonaceous deposit therein, delivering the fluid fuel from the outlet of the retort in which combustion is proceeding to the surface, maintaining at least a second retort fully rubblized between the retort in which combustion is proceeding and retorts in which stoping or rubblization is proceeding, injecting combustion air into the second retort and blocking flow therefrom to maintain the entire second retort at substantially the inlet pressure of the combustion air to prevent flow of combustion products from the first retort to the second retort.

2. A method as set forth in claim 1 in which combustion air is injected into an inlet at the upper end of the retorts, shale oil is delivered from the retorts through an outlet at the lower end thereof, and a combustion front moves downwardly through the retort.

3. A method of producing shale oil as defined in claim 1 in which the first and second retorts are supplied by combustion air from a common air supply drift and the

second retort is supplied from a point upstream of the point from which the first retort is supplied.

4. A method of producing shale oil as defined in claim 2 in which the first and second retorts are supplied by combustion air from a common air supply drift and the second retort is supplied from a point upstream of the point from which the first retort is supplied.

5. A method as set forth in claim 1 in which the combustion air is supplied to the first and second retorts through separate cross drifts from a single air supply drift, and controlling the rate of flow of the air to the first retort by partially closing a remote-controlled door in the cross drift to the first retort whereby the combustion air pressure at the inlet of the second retort is higher than at the inlet of the first retort.

6. A method as set forth in claim 1 in which combustion air is delivered from the surface through a combustion air tunnel extending at an angle to the row of retorts at one end of the row and at substantially the elevation of the upper end of the retorts, an apex drift extends from the combustion air tunnel parallel to the row of retorts at substantially the elevation of the upper end of the retorts in the row, the stoping, rubblization and combustion in the retorts progresses through the retorts successively beginning at the retort farthest from the combustion air tunnel and progressing toward the combustion air tunnel, and following combustion of oil shale in a retort blocking flow of combustion air to such retort and thereafter constructing a rubblized retort under the apex drift opposite the retort in which combustion is completed.

7. A method as set forth in claim 1 characterized by the carbonaceous deposit being oil shale and the fluid fuel being shale oil.

8. A method as set forth in claim 1 characterized by the carbonaceous deposit being an oil reservoir and the fluid fuel being a petroleum oil.

9. A method as set forth in claim 1 characterized by the carbonaceous deposit being coal and the fluid fuel being a gas comprising carbon monoxide as a principal combustible material.

10. In a method of producing shale oil by combustion of oil shale in in-situ retorts in a subsurface oil shale deposit in which each of a plurality of in-situ retorts is subjected to the sequence of preparation for rubblization, rubblization, and ignition of oil shale together with injection of combustion air to maintain combustion in the retort to release shale oil from kerogen, the improvement comprising maintaining between retorts in which combustion is occurring and retorts in which preparation for rubblization and rubblization is occurring at least one fully rubblized retort at substantially the pressure of the combustion air supplied to the retort in which combustion occurs to prevent leakage of combustion products from the retort in which combustion is proceeding to a retort in which preparation for rubblization or rubblization is proceeding.

11. A method for producing shale oil by combustion of oil shale in in-situ retorts as set forth in claim 10 including the steps of supplying combustion air into the at least one rubberized retort and blocking flow of combustion air from the at least one rubberized retort to thereby maintain the combustion air supply pressure in the at least one rubberized retort.

12. In a method of producing a gaseous fuel by partial combustion of coal in in-situ retorts in a subsurface coal deposit in which each of a plurality of in-situ retorts is subjected to the sequence of preparation for rubblization, rubblization, and ignition of the coal together with injection of combustion air to maintain combustion in the retort to release the gaseous fuel from the coal, the improvement comprising maintaining between retorts in which combustion is occurring and retorts in which preparation for rubblization and rubblization is occurring at least one fully rubblized retort at substantially the pressure of the combustion air supplied to the retort in which combustion occurs to prevent leakage of combustion products from the retort in which combustion is proceeding to a retort in which preparation for rubblization or rubblization is proceeding.

13. In a method of producing oil by partial combustion of oil in in-situ retorts in a subsurface petroleum reservoir in which each of a plurality of in-situ retorts is subjected to the sequence of preparation for rubblization, rubblization, and ignition of petroleum together with injection of combustion air to maintain combustion in the retort to move oil from the rubble, the improvement comprising maintaining between retorts in which combustion is occurring and retorts in which preparation for rubblization and rubblization is occurring at least one fully rubblized retort at substantially the pressure of the combustion air supplied to the retort in which combustion occurs to prevent leakage of combustion products from the retort in which combustion is proceeding to a retort in which preparation for rubblization or rubblization is proceeding.

* * * * *

007408

Alberta OIL SANDS INFORMATION CENTRE

United States Patent [19]

Cobbs

[11] **4,165,903**

[45] **Aug. 28, 1979**

[54] **MINE ENHANCED HYDROCARBON RECOVERY TECHNIQUE**

[76] Inventor: **James H. Cobbs**, 5021 S. Fulton St., Tulsa, Okla. 74135

[21] Appl. No.: **875,427**

[22] Filed: **Feb. 6, 1978**

[51] **Int. Cl.**^{2} **E21C 41/10**

[52] **U.S. Cl.** **299/2**; 166/278; 299/19

[58] **Field of Search** 299/2, 11, 12; 166/278

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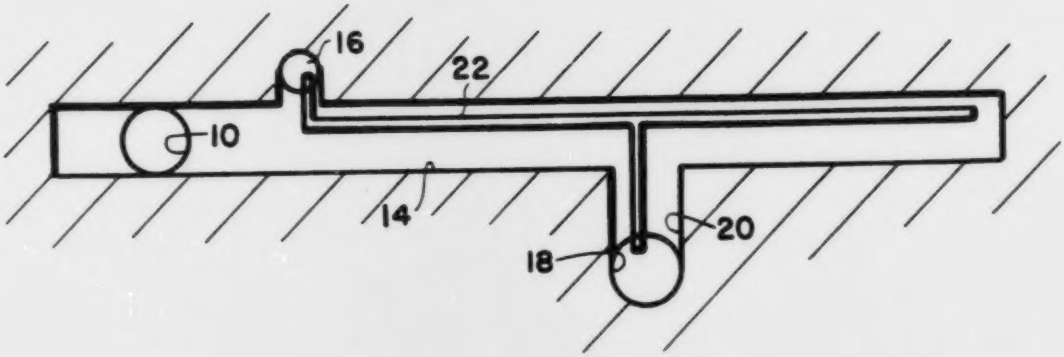
Primary Examiner—Ernest R. Purser

Attorney, Agent, or Firm—Head, Johnson & Chafin

[57] **ABSTRACT**

A method of extracting hydrocarbon from an underground strata, wherein the hydrocarbon has high in situ viscosity, by the steps of forming a vertical access hole from the earth's surface to a point below the strata, the diameter of the access hole being sufficient to permit passage of workmen and machinery, mining an elongated horizontal shaft from the vertical access hole under the strata, establishing at least one drilling station in the horizontal shaft, drilling upwardly from the drilling station a plurality of wells into the hydrocarbon strata, the wells being spaced apart and preferably drilled so as to be substantially vertical in the hydrocarbon strata, injecting a viscosity reducing agent into one or more of the wells to reduce hydrocarbon in the strata to free flowing liquid, withdrawing the free flowing hydrocarbon from the strata through one or more of the wells, and pumping the withdrawn hydrocarbon to the earth's surface.

6 Claims, 12 Drawing Figures



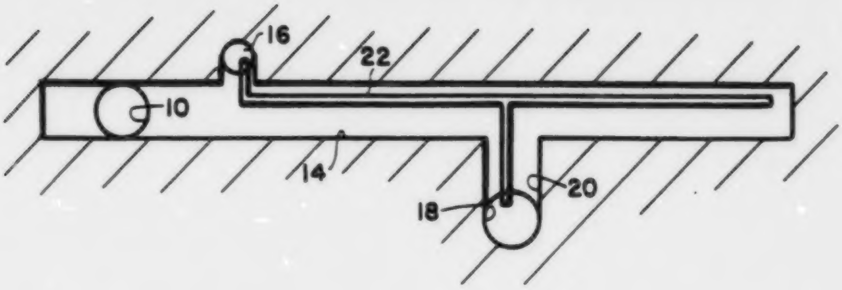

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Fig. 1

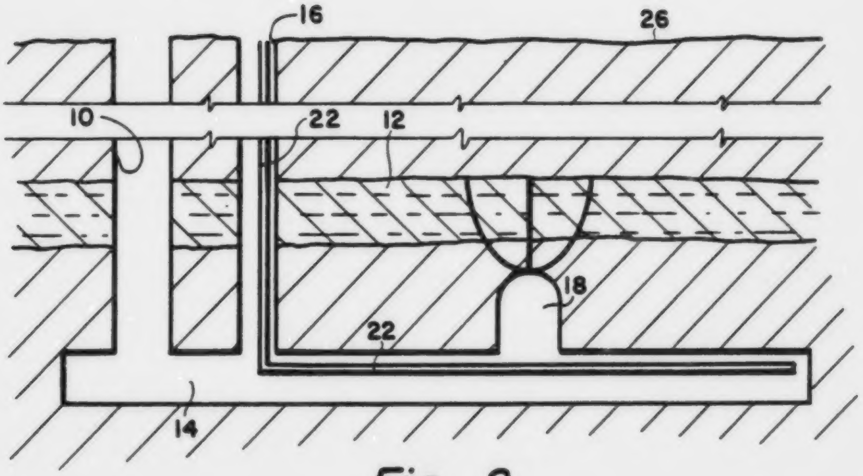
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Fig. 2

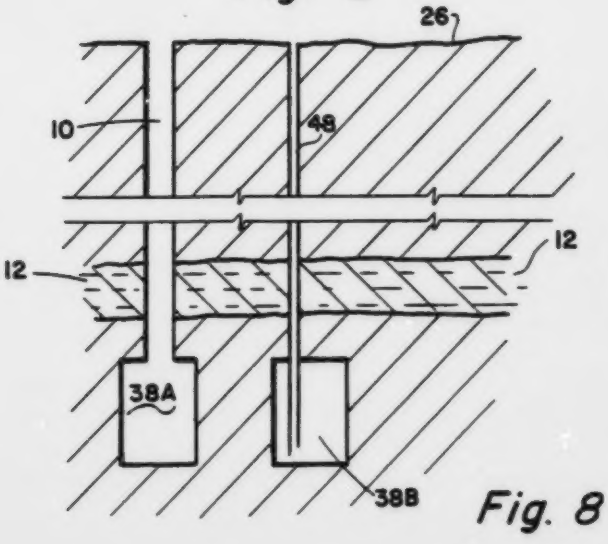
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Fig. 8

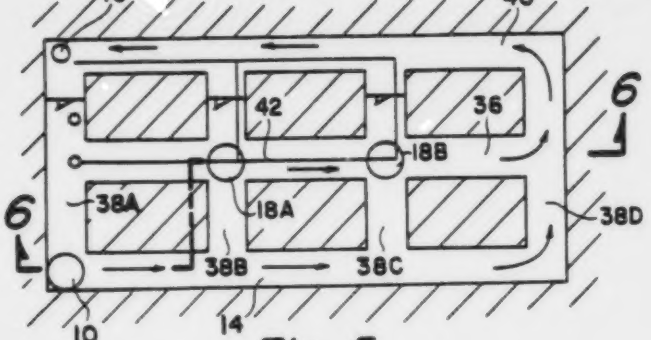
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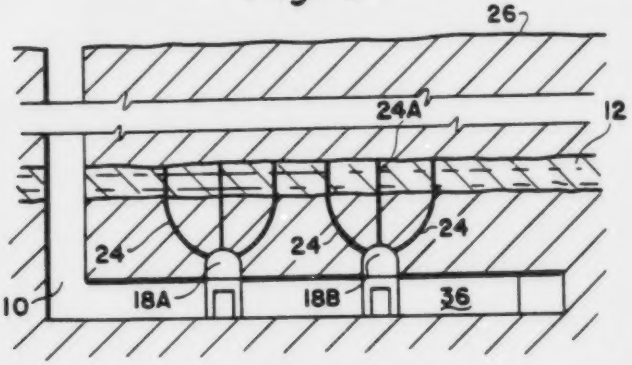
Fig. 5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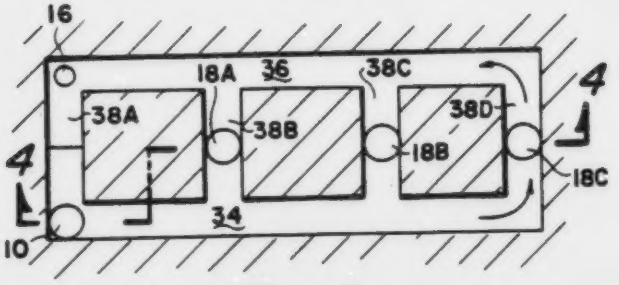
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Fig. 3

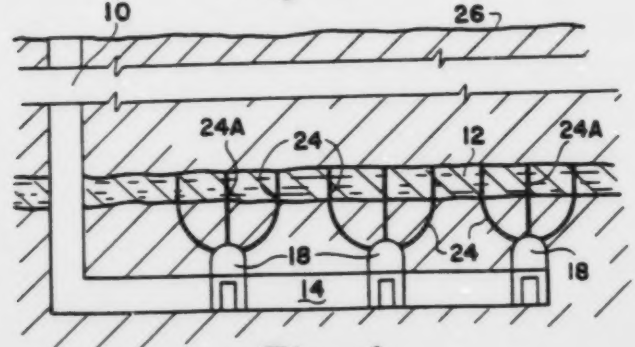
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Fig. 4

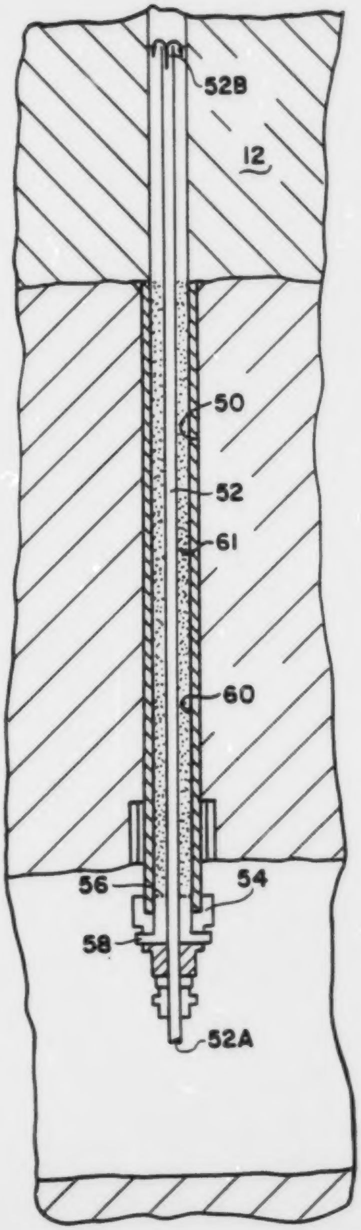
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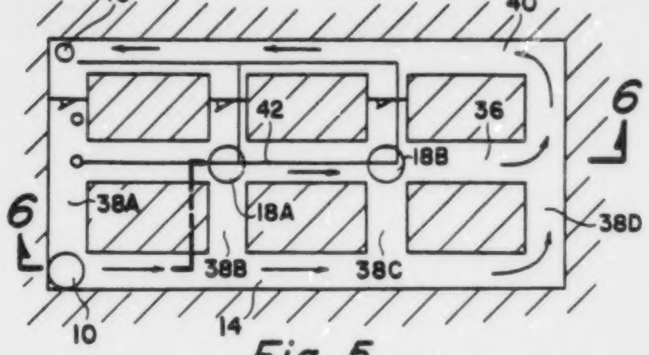
Fig. 12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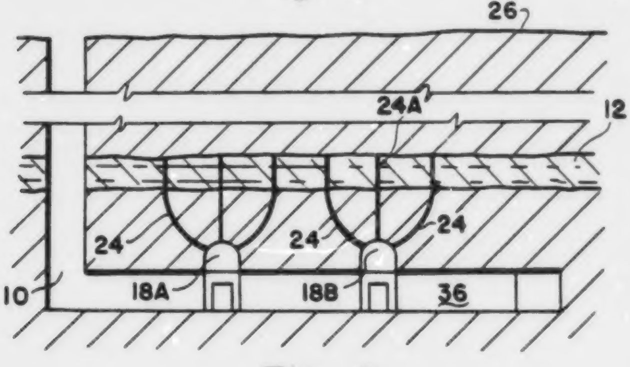
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Fig. 6

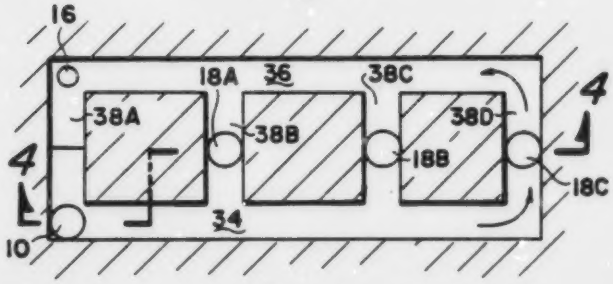
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Fig. 3

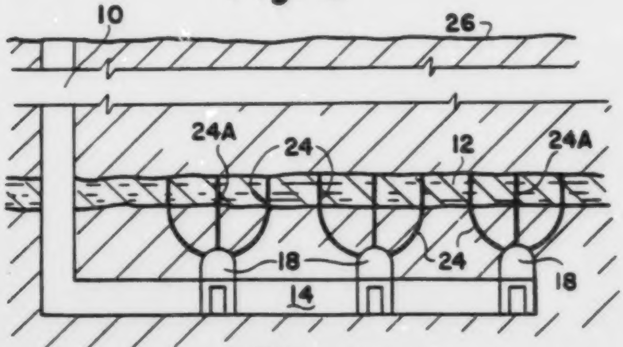
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Fig. 4

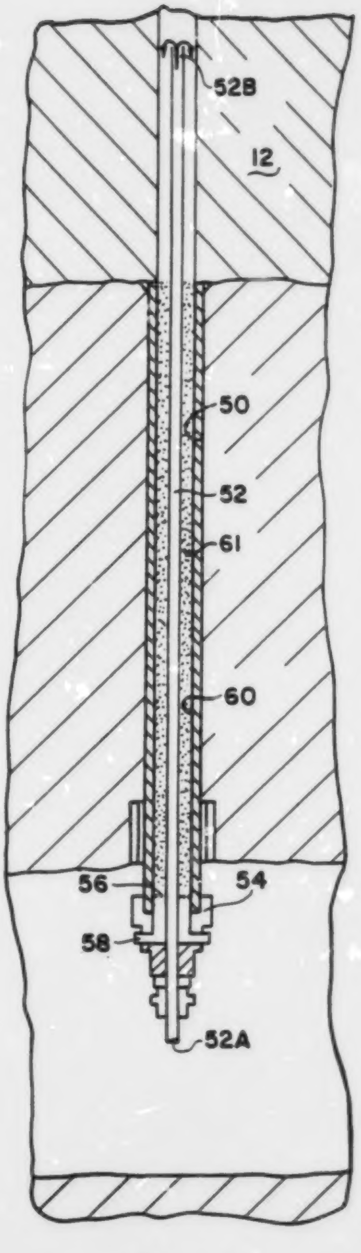
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Fig. 12

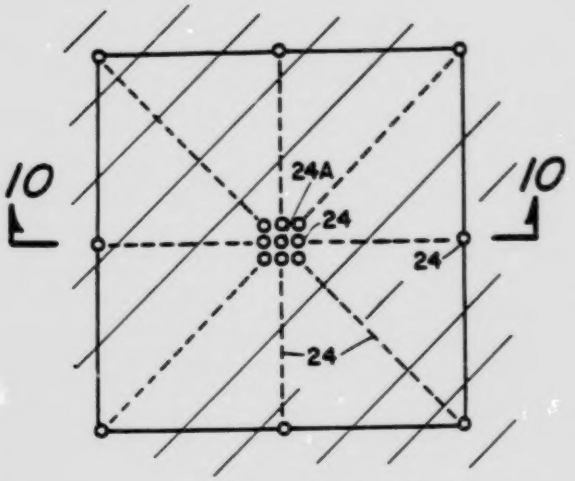
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Fig. 9

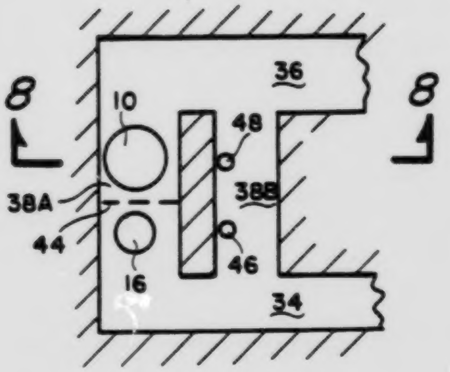
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Fig. 7

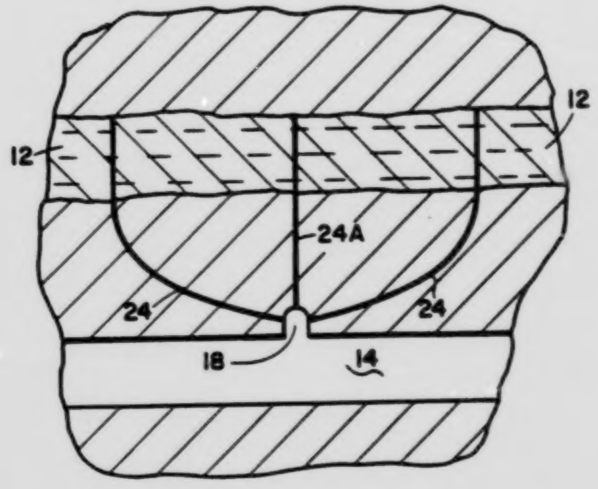
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Fig. 10

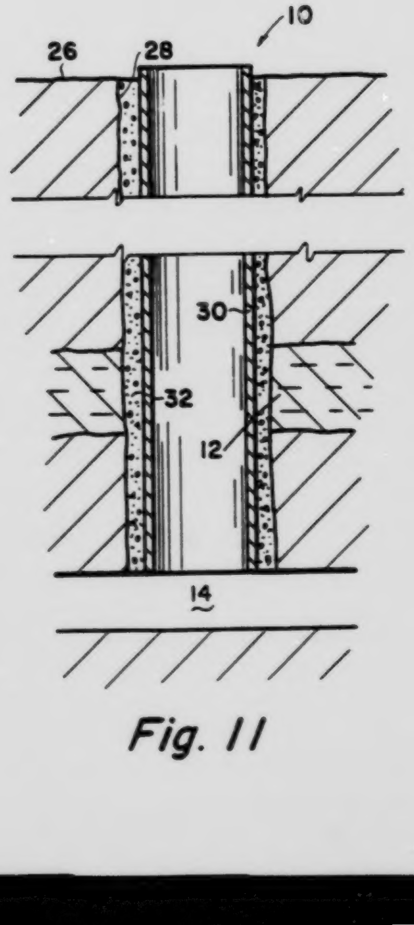
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Fig. 11

MINE ENHANCED HYDROCARBON RECOVERY TECHNIQUE

BACKGROUND AND OBJECTS OF THE INVENTION

Large quantities of petroleum exist in the United States and many other parts of the world which are so viscous that they cannot be recovered using systems which are employed for normal petroleum production. These highly viscous reserves of petroleum are often found in sandstone stratas and because of the high viscosity of the petroleum in the sandstones, such formations are commonly referred to as tar sand. The petroleum in the tar sand may vary from extremely viscous liquids to solids.

Much work has been done towards finding means of recovering the petroleum from tar sands operating from the earth's surface. The general technique is to attempt to change the in situ viscosity of the petroleum in the tar sands to the point where it will flow into a well and can be pumped to the earth's surface. Among the types of endeavors to recover petroleum from tar sands include the injection of solvents, the injection of steam or hot water, and heating the petroleum by in situ combustion. All of these techniques have enjoyed some measure of success when the circumstances are right. However, all efforts to date have not been successful in removing substantial quantities of petroleum from tar sands, and therefore, an improved means needs to be devised so that these large reserves of petroleum can be made available.

It is therefore an object of this invention to provide an improved means of recovering viscous petroleum products from an underground strata. More particularly, an object of this invention is to provide a method of recovering petroleum from an underground strata wherein the in situ viscosity of the petroleum prohibits the petroleum from freely flowing to a well for pumping to the earth's surface, the method including mining shafts below the hydrocarbon bearing strata to provide drilling stations wherein a multiplicity of wells may be drilled upwardly into the petroleum bearing strata, and including improved means of changing the viscosity of the petroleum in the strata so that it can be pumped to the earth's surface. Other objects of the invention include: the development of a mined enhanced recovery process using drilled shafts for access; development and operation for removal of petroleum from positions beneath the hydrocarbon bearing strata; providing methods of multiple point injection of viscosity reducing material and withdrawing hydrocarbons having improved viscosity from a single drilling station; a method of gravel packing of injection or producing wells; and a method of injecting viscosity improving agents and production of petroleum from a common well bore.

These objects, as well as other and more specific objects of the invention will be understood from the following description and claims, taken in conjunction with the attached drawings.

SUMMARY OF THE INVENTION

A method of extracting petroleum from an underground strata having viscous hydrocarbons therein. The method includes first forming a vertical access hole from the earth's surface to a point below the strata. The diameter of the vertical access hole must be sufficient to permit passage of workmen and machinery. Next, a horizontal shaft is mined from the vertical hole beneath the strata. While the method can be practiced utilizing a single horizontal shaft, the preferred arrangement includes two or three horizontal shafts mined parallel to each other and connected with horizontal connecting shafts spaced apart from each other to provide, in essence, a grid of horizontal shafts beneath the structure. Whether one or more horizontal shafts are utilized, at least one drilling station is provided, however, preferably a plurality of drilling stations are utilized. From each drilling station at least one but preferably a plurality of wells are drilled into the strata. The wells are drilled directionally from the drilling station but in a manner such that the wells preferably enter the lower surface of the hydrocarbon strata substantially vertically so that the wells can be drilled upwardly through the hydrocarbon strata in vertical and spaced apart alignment. After the wells are drilled upwardly from the shaft, a viscosity reducing agent is injected through one or more of the wells in each drilling location to reduce the viscosity of the petroleum in the strata. Viscosity reducing agents can include: steam, hot water, solvent, or compressed air or oxygen to sustain in situ combustion. Regardless of the viscosity reducing agent utilized, the viscosity of the hydrocarbon in the formation is reduced to the point where hydrocarbon becomes free flowing. One or more wells from each drilling station is used to withdraw the free flowing hydrocarbons which can then be collected from each drilling station and pumped to the earth's surface. In addition to the access shaft, one or more additional shafts are preferred providing safety exits as well as ventilation. In addition to the basic concept for enhancing the recovery of high viscosity petroleum, methods are provided for completing the drilled wells from each drilling station, including a method of gravel packing the tubing in a drilled hole.

DESCRIPTION OF THE VIEWS

FIG. 1 is a plan view of a layout for mined enhanced recovery of petroleum showing the figuration of a tunnel positioned beneath a petroleum bearing strata and showing the location of shafts which extend from the earth's surface to which the tunnel is connected.

FIG. 2 is an elevational view, shown partially cut away, of the single tunnel arrangement of FIG. 1. The elevational view is not taken with reference to a plane of FIG. 1 but shows the features as if they were in a common vertical plane.

FIG. 3 is a plan view of a recovery system utilizing two main tunnels and showing connecting tunnels providing for three drilling stations.

FIG. 4 is an elevational view of the arrangement of FIG. 3 taken along the line 4—4 of FIG. 3.

FIG. 5 is a plan view of the mining system using three main tunnels with connecting tunnels.

FIG. 6 is an elevational view of the plan of FIG. 5 taken along the line 6—6 of FIG. 5.

FIG. 7 is a segmented plan view of a mining layout employing two main tunnels and showing the arrangement for employing two shafts and two service bore holes.

FIG. 8 is an elevational view taken along the line 8—8 of FIG. 7.

FIG. 9 is a plan view illustrating the well placement of nine wells drilled directionally from a single drilling location.

placed in the hole. The casing will be grouted in place by pumping neat cement grout into the annular space between the casing and the drill hole through a wellhead (not shown) with the grout rising from the collar of the hole to the top of the casing, and when grout reaches the top of the casing, grouting will be halted and operation stopped until the grout has reached its desired degree of set. After the grouting is set, drilling will be resumed till the hole has been extended preferably to the top of the production formation 12.

FIGS. 1, 3, and 5 show mine layouts utilizing single main shaft 10 and a ventilation shaft 16. FIGS. 7 and 8 show a partial layout employing first main shaft 10 and a vent shaft 16 spaced in close proximity to each other. In this arrangement a curtain 44 may be employed between shafts 10 and 16 to force ventilation throughout the balance of the tunnel system. Additional small diameter bore holes may be provided such as an injection fluid bore hole 46 and a produced fluid bore hole 48. As previously stated, when each well 24 or 24A is drilled from a drilling station, it is lined with casing up to the bottom of the production strata 12. In cases where the production strata is unconsolidated, or where in situ combustion is contemplated or the injection of a material which may have detrimental effect upon the cementing material in the tar sands exist, each well may be gravel packed rather than using cement grout to maintain a casing in place.

Referring to FIG. 12, a method of gravel packing will be described. After a drilled bore hole 50 is completed to the top of the production formation 12 a tubing 52 is inserted in the borehole 50 with centralizers (not shown) appropriately spaced to maintain the tubing in the center of the hole. A slurry of graded sand or fine gravel, suspended in a time-sensitive gel of water and an organic gum such as gaurr gum, is injected into the tubing lower end 52A. The slurry will flow out the top end 52B of the tubing and fall back in the bore hole 50 down in the wellhead 54. A screen 56 in the wellhead strains the sand or gravel from the slurry, and the liquid phase can pass out through opening 58 in the wellhead to be recirculated to carry additional sand or gravel into tubing inlet 52A. The gravel packing 60 will build up in the annular area between the exterior of the tubing 52 and the bore hole 50 until it is entirely packed with gravel. When the packing has reached the top of tubing 52 circulation of the slurry will be continued for a certain length of time to further compact the packing until no additional solids can be circulated. The carrier fluid will be circulated until the gelling agent breaks down and viscosity of the fluid reaches that of the original fluid, either oil or water. The packing and tubing then can be drained of the carrier fluid and the well is ready for operation. If desired, the packing can be terminated when it has filled the annulus to the bottom of the hydrocarbon formation 12, as illustrated.

PRODUCING OPERATION

One of the advantages of the method of this invention is the ability to simultaneously inject a viscosity reducing agent into a producing formation 12 and simultaneously withdrawing production from the same well, at least in the early stages of the well. Assume that the specific gravity of the petroleum in production formation 12 is greater than 1, that is, that the API gravity is less than 10 which in turn means that the fluid is heavier than water. The viscosity reducing agent may be such as steam, and the steam may be injected into a well completed as illustrated in FIG. 12, through tubing 52. The steam will contact the formation 12 first at the top. If sufficient heat is absorbed by the contained hydrocarbon in formation 12 to cause it to become mobile, it will flow downwardly in the annular space between the tubing and the bore hole 50 with water condensate rising to the top of the hydrocarbons because of the difference in the specific gravity. The hydrocarbons can then be drawn off from the annulus for accumulation and pumping to the surface. A sensing device (not shown) based on specific gravity differences, diolectric constant differences, electrical capacity differences, or viscosity differences can be placed in the fluid circuit and when water begins to appear in the well effluent, then an annular valve will be closed. Continued injection of steam will recharge the well annulus with liquid hydrocarbon. The injection of steam could also be supplemented with electrical heaters (not shown) attached to the well tubing to maintain hydrocarbon in a fluid state and also to assist in the segregation of the injected water in the fluid hydrocarbon.

Where the petroleum content of strata 12 has a specific gravity lower than that of water, which means that the API gravity is greater than 10, then the injection of the steam can be at the annulus with the hydrocarbons being withdrawn from the top of the strata 12 through tubing string 52. The same type of detecting system may be employed to terminate withdrawal of the fluid when water appears in the effluent until sufficient heat is then introduced by way of the steam to create additional free-flowing hydrocarbon.

Hydrocarbons produced may be withdrawn from the wells through insulated pipe to a central collection tank (not shown) where additional heat can be applied if necessary and the accumulated hydrocarbons pumped to the surface. All systems must be completely closed so that no hydrocarbon vapors or liquids escape underground and thereby cause potential fire or asphixiation hazards.

When wells are produced according to the above method, ultimately the formation adjacent to a well bore will become sufficiently depleted of hydrocarbon that the steam injected will condense and flow out of the withdrawal point without bringing substantial quantities of hydrocarbons with it. When this situation develops, the operation can be changed to a conventional enhanced recovery operation with certain wells converted to injection services exclusively and other wells converted for production exclusively. The same monitoring approaches will be followed so that when water or the other injected viscosity reducing fluid appears in excessive quantities in a producing well it will be automatically shut down to allow the re-establishment of gravitational equilibrium for continued production.

Steam can be generated at the earth's surface and carried through conduits either in shaft 10 or ventilating shaft 16, through injection fluid bore hole 46 as illustrated in FIG. 7. This will minimize the underground space requirement to support the overall operation and eliminate the need of steam generating equipment underground.

While the method of production of wells utilized in the practice of this invention has been discussed wherein steam is used, it can be seen that the same general techniques may be employed if a solvent is used to reduce viscosity or if hot water rather than steam is utilized, or if in situ combustion is initiated in the petroleum bearing strata in which case air or oxygen is in-

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(54) RECOVERY OF HYDROCARBONS BY IN SITU THERMAL EXTRACTION

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BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a process including a shaft or deep boring in the earth, commonly known as wells, for the extraction of fluids from the earth. More particularly, this invention relates to a process for recovering hydrocarbon from a subterranean formation using a well or wells for injection and production and including heating steps.

2. Description of the Prior Art

In many areas of the world, there are large deposits of viscous petroleum. Examples of viscous petroleum deposits include the Athabasca and Peace River regions in Canada, the Jobo region in Venezuela and the Edna and Sisquoc regions in California. These deposits are generally called tar sand deposits due to the high viscosity of the hydrocarbon which they contain. These tar sands may extend for many miles and may occur in varying thickness of up to more than 300 feet. Although tar sands may lie at or near on the eath's surface, generally they are located under an overburden which ranges in thickness from a few feet to several thousand feet. The tar sands located at these depts constitute one of the world's largest presently known petroleum deposits.

The tar sands contain a viscous hydrocarbon material, which is commonly referred to as bitumen, in an amount which ranges from about 5 to about 20 percent by weight. This bitumen is usually immobile at typical reservoir temperatures. For example, at reservoir temperatures of about 48°F, bitumen is immobile, having a viscosity frequently exceeding several thousand poises. At higher temperatures, such as temperatures exceeding

200°F, the bitumen becomes mobile with a viscosity of less than 345 centipoises.

In situ heating is among the most promising methods for recovering bitumen from tar sands because there is no need to move the deposit and thermal energy can substantially reduce the bitumen viscosity. The thermal energy may be introduced to the tar sands in a variety of forms. For example, hot water, in situ combustion, and steam have been suggested to heat tar sands. Although each of these thermal energy agents may be used under certain conditions, steam is generally the most economical and efficient and is clearly the most widely employed thermal energy agent.

Thermal stimulation processes appear promising as one approach for introducing these thermal agents into a formation to facilitate flow and production of bitumen therefrom. In a typical steam stimulation process, steam is injected into a viscous hydrocarbon deposit by means of a well for a period of time after which the steam-saturated formation is allowed to soak for an additional interval prior to placing the well on production.

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To accelerate the input of heat into the formations, it has been proposed to drill horizontally deviated wells or to drill lateral holes outwardly from a main borehole or tunnel. Examples of various thermal systems using horizontal wells are described in U.S. 1,634,236, Ranney; U.S. 1,816,260, Lee; U.S. 2,365,591, Ranney; U.S. 3,024,013, Rogers et al; U.S. 3,338,306, Cook; U.S. 3,960,213, Striegler et al; U.S. ~~[illegible]~~ 3,986,557, Striegler et al; and, Canadian Patent No. 481,151, Ranney. However, processes which use horizontal wells to recover bitumen from tar sand deposits are subject to several drawbacks.

One problem encountered with use of horizontal wells to recover bitumen is the difficulty of passing a heated fluid through the horizontal well. During well completion bitumen will sometimes drain into the well completion assembly. This bitumen may block fluid flow through substantial portions of the horizontal well and thereby decrease heating efficiency.

Another problem encountered with using horizontal wells for recovering bitumen by thermal processes is the difficulty of recovering bitumen which drains into the well. Conventional mechanically energized pumps or pneumatically energized displacement pumps are generally not satisfactory for recovering bitumen from horizontal wells. It has been proposed to use the formation pressure to move the bitumen through the horizontal section of the well and to lift the bitumen to the earth's surface. It is well known, for example, that wells which have been stimulated by "huff and puff" processes sometimes need no artificial lifting due to the hydrocarbon viscosity reduction and to the increased pressure resulting from steam injection. However, to economically recover fluids by this method, the viscosity of the production fluids must be kept relatively low. As bitumen is produced through conventional horizontal wells it has a tendency to cool and to increase in viscosity to the point where the formation pressure will no longer force it to the earth's surface. As a consequence, the efficiency of the steam stimulation process declines.

There is a substantially unfilled need for a thermal system using substantially horizontal wells to effectively recover bitumen from tar sand deposits.

SUMMARY OF THE INVENTION

In accordance with the present invention, hydrocarbons are recovered from a subterranean formation by using the following method. First, a wellbore is drilled to penetrate the formation and to extend into the formation for a suitable distance. Preferably, the wellbore extends substantially horizontally through the formation and near the bottom thereof. The well is completed with a slotted or perforated casing means and with dual concentric tubing strings. The tubing strings, which comprise an inner tubing and a surrounding larger diameter outer tubing are disposed within the casing means. The inner tubing cooperates with the outer tubing to form a first annular space and the outer tubing cooperates with the casing means to form a second annular space. After the wellbore is suitably completed, a heated fluid is circulated within the casing means such that the heated fluid passes through a portion of the first annular space to heat the well and to provide a fluid flow path through both the first and second annular spaces. After the well is suitably heated, a heated fluid is injected into the formation through at least a portion of the second annular space. Subsequently, formation hydrocarbons are produced from formation by means of the well.

In practicing the preferred embodiment of this invention, steam is circulated down the first and second annular spaces and up the inner tubing to heat the well apparatus and to remove hydrocarbons which have accumulated in the second annular space during well completion. Initially, flow through the second annular space may be blocked with viscous hydrocarbons. In that event, steam is circulated through the first annular space to heat and mobilize the viscous hydrocarbons in the second annular space. After steam flow is established through both the first and second annular spaces, steam injection continues to heat the well to a desired temperature. Steam is then injected into the formation through the second annular space. Preferably, during steam injection into the formation, steam condensate and formation hydrocarbons that accumulate in the well are withdrawn continually through the inner tubing. A gas is preferably introduced into the first annular space to insulate the production fluid in the inner tubing from steam in the second annular space. After a suitable injection period the well is shut in and the formation is permitted to heat-soak. Subsequently, the well is placed on production and formation fluids are produced through the inner conduit. To facilitate formation fluid production through the inner tubing, it is sometimes desirable to simultaneously circulate low pressure steam down the second annular space and up the inner tubing.

The practice of this invention substantially reduces problems associated with injecting hot fluid into viscous hydrocarbon-containing formations by means of horizontal wells. The method also facilitates production of formation fluids from formations penetrated by horizontal wells. This method therefore offers significant advantages over the methods used heretofore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 illustrates a vertical cross-section of a well completion apparatus which penetrates a subterranean formation and extends substantially horizontally through the formation.

FIGURE 2 illustrates a vertical section of another embodiment of the well completion apparatus of FIGURE 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGURE 1, the drawing illustrates a subterranean formation 12 which contains tar sands disposed below the earth's surface 10, beneath an overburden 30. A wellbore having a substantially vertical section 11 and a substantially horizontal section 13 has been drilled to penetrate tar sand formation 12 and to extend therethrough. A continuous casing element 14, commonly called a liner, having perforations or slots 15 located between points 16 and 17 is shown extending the entire length of the wellbore. Dual concentric tubing strings 18 and 19 are disposed inside the liner 14. The inner tubing 18 is disposed within the surrounding larger diameter outer tubing 19. Inner tubing 18 cooperates with the outer tubing 19 to form an annular space 20 and the outer tubing 19 cooperates with the casing element 14 to form an annular space 21. The lower end 22 of the inner tubing extends to near the lower end of the casing element 14 and extends for a suitable distance beyond the lower end 24 of the outer tubing 19. Centralizers 23 are installed at various intervals in the annular spaces 20 and 21 to centralize the inner tubing within the outer tubing and to centralize the outer tubing within the liner. It is understood that the centralizers are not continuous and they do not block fluid flow in the annular spaces. The centralizers are appropriately positioned to allow the lower portion of the inner tubing to rest on the bottom of the liner 14. The concentric tubing strings and the liner pass through a wellhead 28 and communicate with the usual production conduits 31-33 having the usual flow control valves 34-36.

In carrying out a preferred embodiment of this invention and referring to FIGURE 1, a wellbore 11 is drilled to penetrate a subterranean tar sand formation 12 and to extend substantially horizontally a suitable distance through the formation near the bottom thereof. The techniques for drilling horizontally deviated wellbores are well known and, therefore, will not be discussed further herein. After the wellbore has been drilled, the drill bit is removed and a perforated liner 14 is positioned inside the drill string. The drill string is then removed and dual concentric tubing strings 18 and 19 are run into the liner. It should be appreciated that the concentric tubing and the liner may be run into the wellbore in any convenient order. Both concentric tubing strings extend to near the lower end of the liner and are in flow communication with the formation through perforations 15. Preferably, the inner tubing 18 is longer than the outer tubing 19 and the lower end 22 of the inner tubing rests on the bottom of the liner as shown in FIGURE 1.

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After the well has been completed, a heated fluid is introduced into the annular spaces 20 and 21 at a sufficient pressure to provide circulation down annular space 20 and/or annular space 21 and up the inner tubing 18. To ~~[illegible]~~ facilitate circulation of the heated fluid, the inner tubing 18 may be withdrawn into the ~~[illegible]~~ outer tubing 19 until circulation is established. The inner tubing may then be gradually extended to its preferred operating position as shown in FIGURE 1. Normally, fluid flow through annular space 20 is established before fluid flow is established through annular space 21 because annular space 21 will normally contain viscous hydrocarbons which have drained into the well during the well completion stage. These viscous hydrocarbons may bank up and form an impermeable barrier to fluid flow through annular space 21. Hot fluid flow through annular space 20 heats and mobilizes the viscous hydrocarbons in annular space 21. After a suitable heating interval, the steam introduced into annular space 21 will displace the bitumen therefrom and sweep it to the earth's surface through inner tubing 18. After fluid flow in annular space 21 is established, hot fluid circulation continues down both annular spaces 20 and 21 and up inner tubing 18 until the well completion assembly is suitably heated. This heating interval may range from 1 to 48 hours, depending on the characteristics of the formation and the design of the well completion apparatus.

After the well is suitably heated a heated fluid, preferably steam, is injected into the annular space 21 under sufficient pressure to force the heated fluid through perforations 15 into the formation 12. The injection pressure of the heated fluid should exceed the formation pressure to the extent required to drive the heated fluid into the formation. Suitable injection pressures range from 100 to 5000 psig, depending upon the depth and permeability of the formation. The pressure of the injected hot fluids may be either above or below the pressure required to fracture the formation. Injection pressures below the fracture pressure of the formation will normally utilize energy more efficiently. Fluid injection into the formation continues for such time as required to raise the temperature of the formation sufficiently to lower the viscosity of the bitumen contained therein and to cause the bitumen to mobilize for a desired distance around the horizontal well. This time interval can be determined by application of heat flow theory and by considering such factors as thermal capacity of tar sands, the thermal content of the injected steam or hot fluid, and the viscosity of the bitumen. Typically, where the hot fluid is steam, the steam injection interval continues for a period from about 1 to about 40 days.

Where the hot fluid injected into the formation is steam, it is preferred that the hot liquids be continuously withdrawn through inner tubing ~~19~~ 18 simultaneously with injection of the steam. These liquids will include steam condensate and formation hydrocarbons which accumulate in the well. The production of this liquid should be regulated to minimize steam flow into the inner tubing.

Preferably, a gas is introduced into annular space 20 to displace heated fluid therefrom. This gas space serves as an insulating medium between steam in annular space 21 and fluids in the inner tubing and thereby aids in maximizing heat efficiency. Suitable gases include natural gas, nitrogen, carbon dioxide, hydrocarbon vapors or any material existing in a gaseous state at the conditions of the annular space 20. In some instances, it may be preferred to continuously inject this gas into annular space 20 at a low flow rate while passing a heated fluid through annular space 21.

Following injection of heated fluid into the formation, it is generally preferred to shut the well in and to permit the formation to "heat soak". During this heat soaking period, the heated volume of the tar sand deposit around the well expands considerably. Although this soak period is not essential to the practice of the invention, it will mobilize larger amounts of bitumen and facilitate gravity drainage of bitumen into the well.

After a suitable soak period, the well is then open to production and the formation fluid are withdrawn through the inner tubing 18. The produced fluids will include a mixture of bitumen, steam and water condensate (including steam condensate). Production of these fluids is carried out with a controlled back-pressure on the well to assure that excess steam does not flow from the reservoir into the well. By reducing steam production, the latent heat of condensation released during the injection period is allowed to remain in the formation. The wellhead pressure is gradually reduced during the well cycle until, at the end of the cycle, it is at as low a level as can be achieved with the wellhead equipment available. This pressure reduction greatly improves gravity drainage of bitumen from the formation. As formation pressure decreases, bitumen is forced out of the formation by the expansion of high pressure steam present in the formation and by the gases generated by vaporization of the hot water and hydrocarbons resulting from pressure reduction. Production fluids will continue to flow from the inner conduit 18 until the formation pressure is no longer sufficient to force the bitumen through the horizontal portion of the well and lift it to the earth's surface. In some cases a vacuum may be applied to the inner tubing after the pressure is released to further facilitate production.

Although not essential to the practice of this invention, it is sometimes desirable during the production stage, to circulate low pressure steam or heated gas down the annular space 21 and up the inner tubing 18. The steam will facilitate upward flow of production fluid through tubing 18 by heating the production fluids and by decreasing the weight of the fluid column within the tubing. Circulation of steam in this manner is particularly desirable if the production fluids are devoid of water which can flash and reduce the average density in the well production tubing or if the production fluids are unusually cool.

When the production declines to an uneconomic level, steam may again be injected into the formation. The above described steps of injecting steam into the formation, permitting the formation to soak and then producing the formation can be repeated cyclically in any manner that proves desirable from an economic standpoint depending on the characteristics of the formation and the bitumen content therein. The length of the injection period, the length of the soak period and the length of the production period will depend upon the characteristics of the formation. These periods may extend over several hours or weeks. It is contemplated that the first cycle will extend for only a few hours and each subsequent cycle will extend for longer time intervals, eventually extending up to several months.

FIGURE 2 illustrates the well completion apparatus for another embodiment of this invention. The well is substantially the same as the well completion assembly illustrated in FIGURE 1 except that the apparatus in FIGURE 2 also includes (1) a packer assembly 28 disposed between the liner 14 and the outer tubing 19 to bar fluid communication in annular space 21 at a point above the uppermost perforations 15 and, (2) a plurality of passages 25 in outer tubing 19 to provide fluid communication between the annular space 20 and the annular space 21 above the packer.

In practicing another embodiment of this invention and referring to FIGURE 2, a wellbore is drilled to penetrate the tar sand formation and to extend substantially horizontally therethrough for a suitable distance. The well is completed in any convenient manner with a slotted or perforated casing element 14, dual concentric tubing strings 18 and 19, and a packer means 28.

After completion of the wellbore, a heated fluid is circulated down the inner tubing 18 and up the annular space 20. Circulation of the heated fluid heats and mobilizes the bitumen which has accumulated in the annular space 21 below the packer 28. The mobilized bitumen drains to the lower end 24 of the outer tubing and is swept to the earth's surface through the annular space 20 and/or through perforations 25 and up the annular space 21 above the packer.

After the well is suitably heated, a heated fluid is injected into the formation through the inner tubing and/or through the annular space 21 above the packer and through passages 25 into annular space ~~21~~ 20. The fluid is injected under sufficient pressure to drive the heated fluid into the formation. Preferably, a gas is introduced into the annular space 20 above the uppermost passages 25. This gas provides insulation between at least a portion the inner tubing and the annular space 21.

After a suitable heating interval, and preferably after permitting the formation to soak for a period of time, the well is placed on production by gradually reducing the pressure in annular space 21. The formation pressure drives production fluids including bitumen through the lower portion of annular space 20 through perforations 25 and up the annular space 21 above the packer to the surface of the earth. Low pressure steam may be injected through inner tubing 18 to heat the production fluids and to provide assistance in lifting the fluids to the surface.

The diameter and length of the horizontal wellbore is not critical to the practice of this invention and will be determined by conventional drilling criteria, the characteristics of the formation, and the economics of a given situation. However, the horizontal portion of the wellbores are typically from about 7 to 11 inches in diameter and from about 200 to 9000 feet in length. To best exploit the effects of gravity in recovering the bitumen, the horizontal section of the well should be formed near the bottom of the hydrocarbon-bearing formation. In addition, the boreholes may have a slightly downward or upward slope depending on the well completion apparatus to facilitate production of the bitumen to the earth's surface.

The composition of the liner and the concentric tubing strings is a function of such factors as the type of injected fluid, flow rate, temperature, and pressure employed in a specific operation. The materials of construction may be the same or different, and may be selected from a wide variety of materials including steel. Sometimes it is desirable for the upper portion of the liner 14 to be firmly secured within the borehole by a cement sheath (not shown).

The steam injected into the formation in the practice of this invention can be generally high or low quality steam. Preferably, the steam is at least 50% quality and more preferably about 70-90%. The steam may be mixed with noncondensable gases such as air or flue gas or with solvents such as methane, ethane, propane, butane, pentane, kerosene, carbon dioxide, carbon disulfide or hydrogen sulfide.

The temperature of the heated fluid injected into the formation can be at any suitable temperature which is capable of mobilizing bitumen in the tar formation. This temperature typically ranges from about 350°F to about 700°F.

Although the above embodiments illustrate horizontal deviated boreholes, drilled from the earth's surface it is within the scope of this invention to carry out the method in a stratum exposed at the face of a slope or cliff or in a stratum penetration by a tunnel or vertical shaft. Moreover, the invention can be carried out in a tar sand stratum exposed by an open pit mining process.

Whereas the invention has been described in connection with the recovery of hydrocarbons from subterranean tar sand deposits, it is also within the scope of this invention to employ the apparatus and method described herein to any subterranean strata containing liquids which can be stimulated by thermal energy.

FIELD EXAMPLE

This invention may be better understood by reference to the following example which is offered only as an illustrative embodiment of the invention and is not intended to be limited or restrictive thereof.

A tar sand formation is located at a depth of 1420 feet and has a thickness of 75 feet. The hydrocarbon viscosity is so high that it is essentially immobile at the formation temperature. The formation temperature is 40°F, the formation pressure is 600 psig, and the formation permeability is 1000 millidarcies.

A wellbore is drilled to the formation and extended substantially horizontally 1275 feet along the bottom of the tar sand formation. Referring to FIGURE 1, the well is completed with a slotted steel liner 14 which is 7 5/8 inches in diameter. The liner slots 15 are about 0.01 inches in width. Dual concentric steel tubing strings are positoned in the liner. The lower end 22 of the inner tubing 18 extends to within 5 feet of the lower end of the liner and the lower end 24 of the outer tubing 19 extends to within 25 feet of the liner's end. The lower portion of the inner tubing rests on the bottom of the slotted liner. The inner tubing has a 2 7/8 inch diameter and the outer tubing has a 5 1/2 inch diameter.

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After completion of the well, steam is introduced into annular spaces 20 and 21 at a pressure of 750 pounds per square inch and condensate is removed through tubing ~~26~~ 18. Steam flow is first established through annular space 20 because steam flow through annular space 21 is blocked with bitumen which has accumulated therein during well completion. After about 8 hours of steaming down annular space 20, steam flow is also established in annular space 21. At this point steam flow through annulus 20 is discontinued and annulus 20 is purged with gas to provide insulation.

Steam circulation continues for 8 hours to heat the well and to remove bitumen therefrom. Thereafter, steam of essentially 100 percent quality is injected into the formation through the annular space 21 at a flow rate of 250,000 lb/hr. at a pressure of 2000 psi for about 10 days; condensate removal is continued through inner tubing 18. Steam injection is then discontinued and the well is shut-in for 7 days.

During this soaking period, liquids including some oil, continue to be produced through the inner tubing 18 with the rate controlled so as to prevent steam bypassing. Following the heat soak period, formation hydrocarbons together with water, steam and gas are allowed to flow up tubing 18 and tubing 19. Tubing 19 is used in addition to 18 in order to reduce pipe friction by providing a greater flow area. In some cases, when productivity is low, it is desirable to use only tubing 18.

During the production cycle, a small flow of natural gas is introduced into annulus 21 to provide insulation.

Hydrocarbon liquids are produced at an average rate of about 1200 barrels per day for a period of 50 days. Although the pressure in the horizontal wellbore gradually decreases, production is maintained by reducing the wellhead pressure. At the end of the production cycle, the bottom hole pressure is less than 100 psig with a wellhead pressure of 30 psig. If percolation becomes poor during the production cycle due to production fluids being devoid of water or due to production fluids having a temperature below the boiling point of water, the flow is assisted by the introduction of either hot gas or steam down the outer annulus 21. At the end of the production cycle, injection of the steam is resumed and the cycle of injection and production is repeated until the reservoir being treated is depleted to the point where further production is no longer economically feasible.

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention and it should be understood that this invention is not to be unduly limited to that set forth herein for illustrative purposes.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for recovering hydrocarbons from a subterranean formation containing viscous hydrocarbons comprising,

drilling a well to said formation and extending the well into said formation;

completing the well with a casing means and with dual concentric tubing strings comprising an inner tubing and a larger diameter outer tubing, the inner tubing forming a first flow path, the inner tubing cooperating with the outer tubing to form a second flow path, and the outer tubing cooperating with the casing means to form a third flow path, said casing means extending substantially the length of said well and containing passages to allow formation hydrocarbons to enter said casing means;

circulating a heated fluid within the casing means until flow of said heated fluid is established in each of said flow paths;

injecting heated fluid into the formation through at least a portion of said third flow path after flow of said heated fluid has been established by circulation within said casing means;

producing formation hdyrocarbons from the formation by means of the well.

2. The method as defined in claim 1 wherein the subterranean formation consists essentially of tar sand.

3. The method as defined in claim 1 wherein the hydrocarbon is substantially bitumen.

4. The method as defined in claim 1 wherein the wellbore extends for at least 200 feet through the formation.

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5. The method as defined in claim 1 wherein said circulated heated fluid is steam.

6. The method as defined in claim 1 wherein said heated fluid injected into said formation comprises steam.

7. The method as defined in claim 6 wherein said heated fluid further comprises hydrogen sulfide.

8. The method as defined in claim 1 wherein the steps of injecting heated fluid into the formation and producing formation hydrocarbons are repeated several times.

9. The method as defined in claim 1 wherein a portion of said well is extended substantially horizontally into said formation.

10. The method as defined in claim 1 wherein the formation hydrocarbons are produced through the first flow path.

11. The method as defined in claim 1 further comprising producing heated liquids through the inner tubing and simultaneously injecting heated fluids into the formation through the third flow path.

12. The method as defined in claim 11 wherein the heated liquid includes steam condensate.

13. The method as defined in claim 1 further comprising introducing an insulating gas into at least a portion of the second flow path to displace the

heated fluid therefrom after circulation of the heated fluid within the casing means.

14. The method as defined in claim 1 wherein the formation hydrocarbons are produced through at least a portion of the third flow path.

15. The method as defined in claim 1 further comprising after circulation of the heated fluid within said casing means introducing into said second flow path an insulating gas.

16. The method as defined in claim 15 wherein said gas is selected from the group consisting of hydrocarbon gases, carbon dioxide or nitrogen.

17. The method as defined in claim 1 further comprising simultaneously with production of bitumen from the formation injecting steam into the third flow path.

18. The method as defined in claim 1 wherein formation hydrocarbons are produced through the first and the second flow paths.

19. The method as defined in claim 18 further comprising injecting a gaseous fluid down the third flow path simultaneously with production of the formation hydrocarbons.

20. A method for recovering viscous hydrocarbons from a subterranean formation containing viscous hydrocarbons comprising,

drilling a borehole to said formation and extending said borehole into said formation;

extending casing means into said wellbore for substantially the entire length thereof, said casing means containing passages to allow formation fluid to enter said casing means;

disposing within said casing means dual concentric tubing strings comprising an inner tubing and a surrounding larger diameter outer tubing, said inner tubing cooperating with said outer tubing to form a first annular space and said outer tubing cooperating with said casing means to form a second annular space;

circulating a heated fluid down said first annular space and up said inner tubing to heat said inner and outer tubings;

introducing a gas into the first annular space to displace said heated fluid therefrom;

injecting a second heated fluid into the formation through said second annular space;

producing formation hydrocarbons from the formation through the inner tubing.

21. A method for recovering viscous hydrocarbons from a viscous hydrocarbon-bearing formation comprising,

drilling a wellbore to said formation and extending said wellbore through the formation;

completing the wellbore with a casing means containing passages to allow formation hydrocarbons to flow into the casing means, with dual concentric tubing comprising an inner tubing and a larger diameter outer tubing disposed in said casing means, and with a packer means disposed between the outer tubing and casing means at a point above the passages of said casing means, said inner tubing cooperating with said outer tubing to form a first annular space and said outer tubing cooperating with said casing means to form a second annular space, said outer tubing containing passages at a point above the packer to allow fluid flow between the first annular space and the portion of the second annular space above the packer;

circulating a heated fluid in the casing means such that the heated fluid flows through at least a portion of the second annular space;

injecting a second heated fluid into the formation through at least a portion of the second annular space below the packer;

producing hydrocarbons from the formation through at least one of the flow conduits.

22. A method for recovering bitumen from a subterranean tar sand formation comprising,

drilling a wellbore to the tar sand formation and extending the wellbore into the formation;

completing the wellbore with a casing means and disposed in said casing means, dual concentric tubing strings comprising an inner tubing and a larger diameter outer tubing, said inner tubing cooperating with said outer tubing to form a first annular space and said outer tubing cooperating with said casing means to form a second annular space, said casing means having passages to allow the formation bitumen to flow into the casing means;

circulating a heated fluid down said first annular space and up said inner tubing;

circulating the heated fluid down said second annular space and up the inner tubing;

thereafter injecting a heated fluid into the formation through the second annular space;

producing bitumen from the formation through the first flow path.

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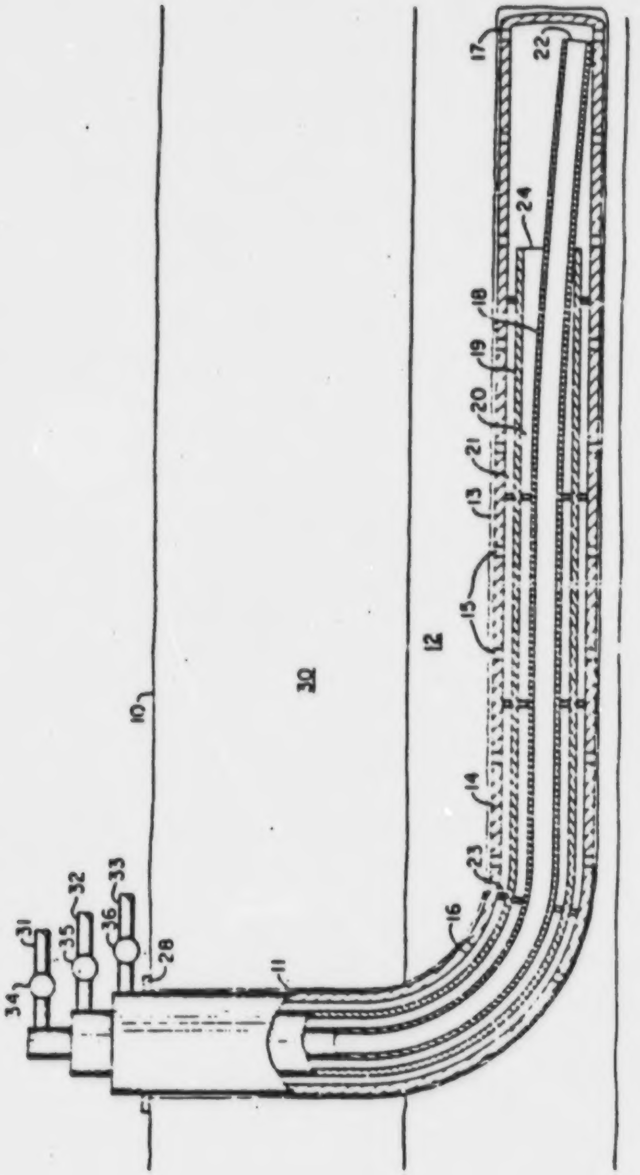

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FIG. 1

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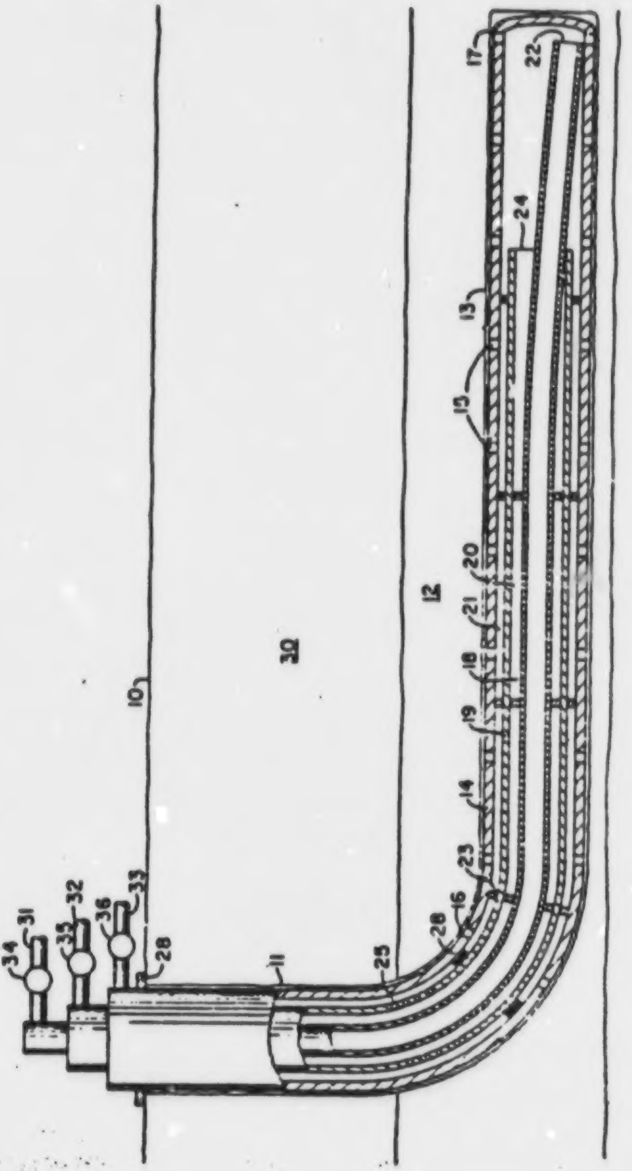

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FIG. 2

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Alberta OIL SANDS
INFORMATION CENTRE

⑪ Ⓐ No. 1072005

㊺ ISSUED 800219

(52) CLASS 166-33
C.R. CL.

(51) INT. CL. ^{2} E21B 43/24

⑲ (CA) CANADIAN PATENT ⑫

(54) METHOD FOR OIL RECOVERY USING A HORIZONTAL WELL WITH INDIRECT HEATING

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Canada

Granted to Exxon Production Research
Company, U. S. A.

㉑ APPLICATION No. 294,296
㉒ FILED 780104

㉚ PRIORITY DATE U. S. A. (777,295) 770314

No. OF CLAIMS 16

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CCA-274 (5-79)

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a process including a shaft or deep boring in the earth, commonly known as wells, for the extraction of fluids from the earth. More particularly, this invention relates to a process for recovering hydrocarbons from a subterranean formation using a well or wells for injection and production and including heating steps.

2. Description of the Prior Art

In many areas of the world, there are large deposits of viscous petroleum. Examples of viscous petroleum deposits include the Athabasca and Peace River regions in Canada, the Jobo region in Venezuela and the Edna and Sisquoc regions in California. These deposits are generally called tar sand deposits due to the high viscosity of the hydrocarbons which they contain. These tar sands may extend for many miles and may occur in varying thickness of up to more than 300 feet. Although tar sands may lie on or near the earth's surface, generally they are located under an overburden which ranges in thickness from a few feet to several thousand feet. The tar sands located at these depths constitute one of the world's largest presently known petroleum deposits.

The tar sands contain a viscous hydrocarbon material, which is generally referred to as bitumen, in an amount which ranges from about 5 to about 20 percent by weight. This bitumen is usually immobile at typical reservoir temperatures. For example, at reservoir temperatures of about 48°F, bitumen is immobile, having a viscosity frequently exceeding several thousand poises. At higher temperatures, such as temperatures exceeding 200°F, the bitumen becomes mobile with a viscosity of less than 345 centipoises.

In situ heating is among the most promising methods for recovering bitumen from tar sands because there is no need to move the deposit and because can substantially reduce the viscosity of bitumen. The thermal energy may be introduced into the tar sands in a variety of forms. For example, hot water, in situ combustion, and steam have been suggested to heat tar sands. Although each of these thermal energy agents may be used under certain conditions, steam is generally the most economical and efficient.

Thermal stimulation processes are among the most promising of the in situ methods for heating tar sand formations. In one process, commonly referred to as the "huff and puff" process, steam is injected through a well and into a viscous hydrocarbon deposit for a period of time. The well is then shut in to permit the steam to heat the oil. Subsequently, the well is placed on production.

To accelerate the input of heated fluids into the formations, it has been proposed to drill horizontally deviated wells or to drill lateral holes outwardly from a main borehole or tunnel. Examples of various thermal systems using horizontal wells are described in U.S. 1,634,236, Ranney; U.S. 1,816,260, Lee; 2,365,591, Ranney; U.S. 3,024,013, Rogers et al; U.S. 3,338,306, Cook; U.S. 3,960.213, Striegler et al; U.S. 3,986,557, Striegler et al; Canadian Patent No. 481,151, Ranney; and German Patent 1,163,750, Heuckeroth. However, injection of heated fluids into tar sand formation through horizontal wells has not been developed commercially. One difficulty with these prior art methods is that hydrocarbons do not flow into the horizontal well in economic quantities.

There is a substantially unfilled need for an improved thermal method for effectively recovering viscous hydrocarbons from subterranean formation.

SUMMARY OF THE INVENTION

In accordance with the practice of this invention, hydrocarbons are recovered from a subterranean formation by the following method. A heated fluid is injected into the formation by means of a perforated conduit which is disposed in a substantially horizontal manner within the formation to heat hydrocarbons within the formation and to render the hydrocarbons more flowable. Injection of the heated fluid is then terminated to permit formation fluids, including the heated formation hydrocarbons, to flow into the perforated conduit. Subsequently, formation fluids within thw perforated conduit are heated to a temperature sufficient to vaporize at least a portion of said formation fluids to cause such vaporized fluids to pass from the perforated conduit into the formation. These vaporized fluids further heat the formation hydrocarbons to render the hydrocarbons more flowable. Heated formation fluids including heated formation hydrocarbons are then withdrawn from the formation by means of the perforated conduit.

In the practice of the preferred embodiment of this invention, a perforated conduit is extended substantially horizontally into a tar sand deposit from a tunnel which is disposed near the bottom of the tar sand deposit. Disposed in the perforated conduit are dual concentric conduits which comprise an inner conduit and a surrounding larger diameter intermediate conduit. The intermediate conduit and the perforated conduit cooperate to form an annular space and the inner conduit and the intermediate conduit cooperate to provide a continuous enclosed fluid flow path through the intermediate conduit. Steam and optionally a solvent is injected into the formation through the annular space to reduce the viscosity of formation hydrocarbons. After a suitable injection interval, formation fluids are permitted to drain into the annular space. Subsequently, steam or another heating medium is passed through the intermediate conduit to heat indirectly the drained fluids in the annular space. During this indirect heating, additional steam or hydrocarbon vapors are produced by boiling and these vapors pass into the surrounding reservoir heating and diluting the bitumen therein. After a suitable indirect heating period, formation hydrocarbons are drained from the annular space to the tunnel and are pumped through suitable conduits to a processing unit.

The practice of this invention enhances drainage of viscous hydrocarbon into the horizontal well. The invention will therefore be seen to offer significant advantages over conventional methods for recovering viscous hydrocarbons.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a vertical cross-sectional view illustrating a completion assembly for a horizontal conduit extending from a tunnel into a tar sand deposit.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the FIGURE, a description of the preferred embodiment of the method of this invention will be described in an unconsolidated tar sand formation. A subterranean formation 11 is shown which contains tar sands such as Athabasca tar sands, disposed below the earth's surface (not shown), beneath an overburden 13.

As the first step of this embodiment, a perforated conduit 14 is disposed in the tar sand deposit 11. The FIGURE illustrates a substantially horizontal conduit 14 which extends from a tunnel 15 which is positioned approximately transverse to the conduit 14. The tunnel wall 16 may be composed of any suitable material such as cement to prevent unrestricted fluid communication between the tunnel and the formation. The perforated conduit 14 is positioned through the tunnel wall and is sealed to the wall in any convenient manner to prevent unrestricted ingress of fluid into the tunnel. The perforated conduit 14 may be extended into the tar sands by any convenient means. For example, a wellbore may be drilled and a perforated liner may then be inserted into the well or the conduit may be driven into the formation with a vibrator. The art of forming tunnels in tar sands and of extending horizontal conduits from tunnels is well known.

The conduit 14 contains slots or perforations 17 to provide fluid communication between the interior of the conduit and the tar sand deposit. Inlet and outlet pipes 26 and 27 provide fluid communication into and out of the conduit 14. Disposed within the perforated conduit 14 is a heater assembly 20 which comprises dual concentric pipes 21 and 22. The pipe 21 extends substantially the entire length of conduit 14 and is closed at the end which is remote from the tunnel. Pipe 21 cooperates with the perforated conduit 14 to form an annular space 18. Pipe 22 is disposed coaxially within pipe 21 and is open at the end remote from the tunnel. Centralizer baffles 23 are installed at various intervals in the annular spaces between the pipe 21 and perforated conduit 14 and between the pipe 21 and pipe 22 to centralize pipe 22 within pipe 21 and to centralize pipe 21 within the perforated conduit 14. These centralizers are not continuous and they do not block fluid flow in the annular space. Pipes 21 and 22 cooperate with each other to form a continuous enclosed fluid flow path. Fluids may be introduced into either pipe 21 or pipe 22 and will exit through the other of these pipes. Supply of fluids to and from pipes 21 and 22 is accomplished by conduits 24 and 25 which are connected through suitable piping (not shown) to a source of heated fluid.

After the perforated conduit is suitably completed, a heated fluid is injected into the formation through conduit 14. Referring to the FIGURE, the heated fluid enters conduit 14 via pipe 27 and passes through passages 17 into the formation. The heating fluid may be any suitable fluid which is capable of heating bitumen in the formation to a sufficient temperature to cause the bitumen to gravitate downwardly into the conduit 14. For example, the fluid may be steam or may be a solvent vapor or may be a mixture of steam and air, or a mixture of steam and solvent such as carbon disulfide, hydrogen sulfide, naphtha, cracked naphtha, C_3, C_4, or C_5 hydrocarbons, toluene, xylene or benzene.

Following a suitable injection period, the heated fluid injection is discontinued and formation fluids including bitumen are permitted to drain into the annular space. Heated fluid is then circulated through pipes 21 and 22 to indirectly or conductively heat the fluids in annular space 18. Circulation of heated fluid through pipes 21 and 22 is continued with the fluid at a temperature sufficient to vaporize a portion of the drained fluids. The temperature of the circulated heated fluid will depend upon the boiling temperature in the annular space. This boiling temperature will typically range from about 250°F to about 750°F. The heated fluid in conduits 21 and 22 has a temperature higher than the fluids in annular space 18.

After a suitable indirect heating interval, bitumen is recovered from the formation by allowing it to drain through annular space 18 into conduit 26 from which it is pumped through suitable conduits to a conventional processing unit or is passed to storage.

The heated fluid circulated through heating assembly 20 may be any heat carrying gas or liquid which is capable of boiling fluids in annular space 18. Steam is suitable because it is relatively economical to produce and the temperature of the steam in the heater assembly will be substantially uniform throughout. In some cases other heat transfer agents such as diphenyl/diphenyl oxides mixtures may be preferable.

The diameter and length of the perforated conduit 14 will depend on the characteristics of the formation, conventional drilling criteria and economics of a given situation. However, the perforated conduits are typically from about 7 to 18 inches in diameter and from about 200 to 9000 feet in length.

To best exploit the effects of gravity in recovering the bitumen, the slotted or perforated conduit should be formed towards the bottom of the hydrocarbon-bearing formation. The production rate will usually be enhanced by locating the perforated conduit 10 to 50 feet above the bottom of the bitumen bearing zone. In addition, the borehole should be drilled slightly downward or upward depending on the well completion apparatus, to facilitate production of the bitumen to the earth's surface. With the configuration shown in the Figure, the borehole should slope upwards from the tunnel so as to allow gravity to move liquids towards the tunnel.

The composition of the liner and the concentric tubing string is a function of such factors as the type of injected fluid, flow rate, temperature, and pressure employed in a specific operation. The materials of construction may be the same or different, and may be selected from a wide variety of materials, including steel. The perforations in the casing would normally start several feet from the tunnel in order to reduce heating of the tunnel itself.

The steam injected into the formation, in the practice of this invention, can be generally high or low quality steam. Preferably, the steam is at least 50% quality and more preferably from about 70 to 100 percent. The steam may be mixed with noncondensable gases such as air or flue gas, or with solvents such as methane, ethane, propane, butane, pentane, naphtha, cracked naphthas, kerosene, carbon dioxide, carbon disulfide or hydrogen sulfide. A mixture of volatile solvents and steam will increase hydrocarbon drainage into the well. Volatile solvents injected into the formation with the steam will flow upwards into the formation to dilute the bitumen and thereby aid in reducing its viscosity. These solvents will tend to accumulate and reflux within the hot zone of the reservoir. Thus, the hot zone of the formation may contain relatively high concentrations of solvent with only a relatively small concentration of solvent injected with the steam. This is particularly important if reactive solvents such as hydrogen sulfide are to be employed.

The temperature of the fluid injected into the formation can be of any suitable temperature which is capable of mobilizing bitumen in the tar sand formation. In many instances, it will be desirable that the hot fluid have a temperature between about 250°F and about 600°F. Although operation with colder fluids is possible, this will tend to increase the requirements for indirect heat.

It should be understood any type of heating means which is capable of vaporizing fluids in the perforated conduit 14 can be used in the practice of this invention. A heating means such as an electrical heater can be associated with or located within the perforated conduit. The invention is, therefore, not limited to the heater assembly as described for the preferred embodiment.

The indirect heating of fluids in the annular space 14 facilitates drainage of bitumen into the well during the indirect heating stage. At least a portion of the water and hydrocarbons in the conduit are vaporized. The steam and hydrocarbon vapors help carry heat from the well into the formation and reduce viscosity of a larger amount of bitumen in the well.

The indirect heating stage of this invention also facilitates hydrocarbon drainage into the well by increasing the oil saturation in the reservoir pore spaces around the well. In conventional steam stimulation processes, the steam injection into the well tends to strip the oil on the reservoir pore spaces adjacent the well. These pore spaces then become water saturated and flow of oil into the well from the reservoir is restricted because of capillary pressure effects. During the indirect heating stage, however, the water in at least part of these pore spaces is vaporized and oil is permitted to occupy these spaces.

In another embodiment of this invention, after a heated fluid has been injected into the formation for a suitable time interval, formation fluids including bitumen may be produced from the formation by means of conduit 14. When production rates decrease to an uneconomical level, production is stopped and heated fluid is circulated through pipes 21 and 22 to indirectly heat the fluids in annular space 18. After a suitable indirect heating interval, bitumen is again produced from the formation by means of conduit 14.

In the broadest aspect of this invention, the conduit 14 can be disposed in any subterranean formation. The conduit can be extended, for example, from a vertical or deviated borehole which extends into the deposit, from a deposit which outcrops along a cliff, from a trench which extends from the earth's surface into the tar sands, or from a tunnel which is formed in the formation as illustrated in the FIGURE. Other means, of course, can be used to provide an exposed working surface.

Although the invention has been described in connection with the recovery of hydrocarbons from subterranean tar sand formations, it is also within the scope of this invention to employ the apparatus and method described herein to recover any liquids from any subterranean strata which can be stimulated by thermal energy. This invention can also be employed to recover hydrocarbons of much higher API gravity, e.g. 25° to 40° API.

FIELD EXAMPLE

This invention may be better understood by reference to the following example which is offered only as an illustrative embodiment of the invention and is not intended to be limited or restrictive thereof.

A tar sand formation is located at a depth of 1420 feet and has a thickness of 75 feet. The hydrocarbon viscosity is so high that it is almost immobile at the formation temperature. The formation temperature is 40°F and the formation pressure is 600 psig and the formation permeability is 2000 millidarcies.

A tunnel is formed in the tar sand formation along the bottom thereof by conventional means. A wellbore is drilled in an upward direction 1° from the horizontal into the formation for a distance of 2000 feet. Referring to the FIGURE, the well is completed with a steel liner which is slotted from a distance of 100 feet from the tunnel to the end. The liner slots 17 are about 0.03 inches in width. Dual concentric tubing string 21 and 22 are positioned in the liner and extend to approximately the entire length of the liner. Centralizers 23 centralize conduit 21 coaxially within liner 14 and centralize conduit 22 coaxially within conduit 21. Conduit 21 cooperates with perforated conduit 14 to form the annular space 18. Conduit 22 has a 3 1/2 inch diameter and conduit 21 has a 5 1/2 inch diameter and perforated conduit 14 has a 12 inch diameter. After completion of the perforated conduit, steam is introduced into the annular space 18 at a pressure of 1000 pounds per square inch for 10 hours. Steam injection is then discontinued and the well is shut in for 3 hours. During this soak period, the bitumen and steam condensate drain into the annular space 18. Subsequently, steam is circulated through conduit 22 into the annular space between conduits 21 and 22, and steam condensate is withdrawn through conduit 25. The steam is circulated at a pressure of 1000 psi for about 1 hour. Bitumen is then allowed to drain through annular space 18 through conduit 26 and then to storage or other production facilities. At the end of the production cycle, the steps of injecting steam in the formation, allowing the formation fluids to drain into the annular space, heating indirectly the formation fluids to force at least a portion of fluids into the formation, and recovering the fluids are repeated with each cycle length being increased until the reservoir being treated is depleted to the point where further production is no longer economically feasible.

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and the spirit of this invention, and it should be understood that this invention is not to be unduly limited to that set forth herein for illustrative purposes.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for recovering hydrocarbons from a subterranean formation comprising

injecting a heated fluid into the formation by means of a perforated conduit which is disposed in a substantially horizontal manner within the formation to heat hydrocarbons within the formation to render the hydrocarbons more flowable;

terminating injection of the heated fluid into the formation to permit formation fluid including the heated formation hydrocarbons to flow into the perforated conduit;

heating the formation fluids within the perforated conduit by conduction to a temperature sufficient to vaporize at least a portion of said formation fluids to cause such vaporized fluids to pass from the perforated conduit and into the formation to further heat formation hydrocarbons to render the hydrocarbons more flowable; and

withdrawing heated formation fluids including heated formation hydrocarbons from the formation by means of the perforated conduit.

2. The method as defined in Claim 1 wherein the heated fluid is steam.

3. A method as defined in Claim 1 wherein the fluid injected into the formation is selected from the group consisting of steam, solvent vapors, a mixture of steam and air, or a mixture of steam and solvent.

4. The method as defined in Claim 3 wherein the solvent is selected from the group consisting of carbon disulfide, hydrogen sulfide, ~~naptha~~ naphtha, cracked ~~naptha~~ naphtha, toluene, xylene or benzene.

1/7 Jul 2, 1977

5. The method as defined in Claim 1 further comprising repeating the steps of injecting a heated fluid into the formation, terminating fluid injection to permit formation fluids to drain into said conduit and heating the formation fluids within in said conduit.

6. The method as defined in Claim 1 wherein the formation fluids within the perforated conduit are heated by a heating means.

7. The method as defined in Claim 6 wherein the heating means heats substantially the entire portion of the perforated conduit.

8. The method as defined in Claim 1 further comprising before heating the formation fluids within the perforated conduit, withdrawing formation fluids including heated formation hydrocarbons from the formation by means of the perforated conduit.

9. A method for recovering viscous hydrocarbons from a subterranean formation containing viscous hydrocarbons comprising

positioning a perforated first conduit substantially horizontally into the formation;

disposing inside the perforated conduit dual concentric conduits comprising an inner conduit and a surrounding larger diameter intermediate conduit, said intermediate conduit and said perforated conduit cooperating to form an annular space, said inner conduit and said intermediate conduit cooperating to provide continuous enclosed fluid flow path through said inner and intermediate conduits;

injecting a heated fluid into the formation through said annular space and thereby reducing the viscosity of the formation hydrocarbons;

permitting fluids including formation hydrocarbons to drain into said annular space;

circulating a heated fluid through said inner and intermediate conduits to heat indirectly the drained fluids in said annular space; and

recovering the formation hydrocarbons from said annular space.

10. The method as defined in Claim 9 wherein the heated fluid injected into the formation is steam.

11. A method as defined in Claim 9 wherein the heated fluid injected into the formation is selected from the group consisting of steam, a mixture of steam and air, or a mixture of steam and solvent.

12. The method as defined in Claim 11 wherein the solvent is selected from the group consisting of carbon disulfide, hydrogen sulfide, naphtha, C_3, C_4, or C_5, hydrocarbons, toluene, xylene or benzene.

13. In a method for recovering viscous petroleum including bitumen from a subterranean viscous petroleum containing formation including a tar sand deposit, said formation being penetrated by a perforated conduit which extends substantially horizontally therethrough, said perforated conduit being completed by dual concentric conduits comprising an inner conduit and a surrounding larger diameter intermediate conduit, said intermediate conduit and said perforated conduit cooperating to form an annular space, said inner conduit and said intermediate conduit cooperating to provide a continuous enclosed fluid flow path through said inner and intermediate conduits, said recovery method being of the type wherein a fluid is injected into the well for the purpose of increasing the mobility of petroleum contained in the formation, the improvement which comprises

injecting a heated fluid into the formation through said annular space and thereby reducing the viscosity of the formation hydrocarbons;

permitting fluids including formation hydrocarbons to drain into said annular space;

circulating a heated fluid through said inner and intermediate conduits to heat indirectly the drained fluids in said annular space; and

recovering the formation hydrocarbons from said annular space.

14. The method as defined in Claim 13 wherein the heated fluid injected into the formation is steam.

15. A method as defined in Claim 13 wherein the heated fluid circulated through said inner and said intermediate conduits is steam.

16. In a method for recovering viscous hydrocarbons from a subterranean formation comprising

positioning a perforated conduit substantially horizontally into said formation;

disposing in said conduit a heating means to heat fluids in said conduit;

injecting a fluid into the formation through said perforated conduit;

permitting fluids including the formation hydrocarbons to flow into said conduit;

heating said fluid in said conduit by conduction with said heating means to a temperature such that at least a portion of the drained fluid passes into said formation; and

recovering formation hydrocarbons from the formation through said conduit.

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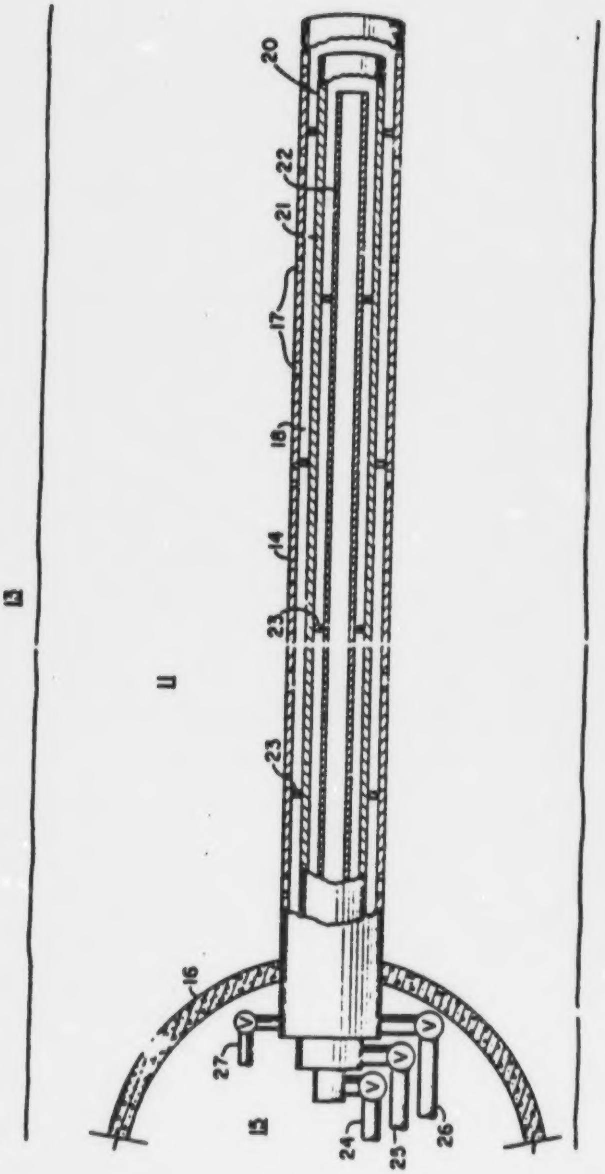

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Scott & Aylen

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United States Patent [19]

Ruzin et al.

[11] **4,227,743**

[45] **Oct. 14, 1980**

[54] **METHOD OF THERMAL-MINE RECOVERY OF OIL AND FLUENT BITUMENS**

[76] Inventors: **Leonid M. Ruzin**, poselok Yarega, ulitsa Kosmonavtov 5, kv. 26; **Jury A. Spiridonov**, ulitsa Chibjusskaya, 7, kv. 81.; **Gennady S. Chuprov**, prospekt Lenina, 37/10, kv. 72.; **Boris A. Tjunkin**, ulitsa Oplesnina, 30, kv. 33., all of Komi ASSR, Ukhta; **Vladimir P. Tabakov**, ulitsa Soffii Kovalevskoi, 4-a, kv. 125., Moscow, all of U.S.S.R.

[21] Appl. No.: **943,558**

[22] Filed: **Sep. 15, 1978**

[51] **Int. Cl.**^{2} **E21C 41/10**
[52] **U.S. Cl.** **299/2; 166/272**
[58] **Field of Search** 299/2; 166/272

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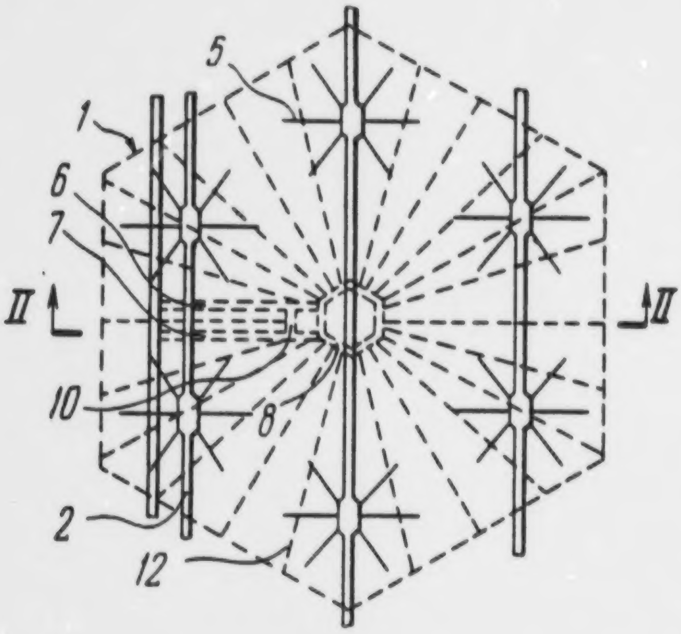
Primary Examiner—Ernest R. Purser

Attorney, Agent, or Firm—Steinberg & Blake

[57] **ABSTRACT**

The method of thermal-mine recovery of oil and fluent bitumens or kerogens includes providing a system of mine workings above an oil-bearing formation and drilling from these workings and from the ground surface a series of injection wells into the oil-bearing formation. An operation gallery is provided within the oil-bearing formation, from which a system of horizontal and inclined recovery wells is drilled. Then a heat carrier is positively injected into the oil-bearing formation to heat it to a temperature whereat the oil attains the required fluidity within the formation. Then a fluid is charged into the formation to force the oil from the oil-bearing formation into the horizontal and inclined recovery wells, toward the operation gallery, from which the oil is directed to the ground surface. The improvement of the method resides in that the heat carrier is injected into the formation through the horizontal and inclined recovery wells extending substantially across the predominant direction of the highly permeable zones of the oil-bearing formation, and, following the heating of the formation to the abovesaid temperature, the injection of the heat carrier is terminated, and the fluid is charged into the injection wells having minimized association with the highly permeable zones of the oil-bearing formation, to force the oil from the oil-bearing formation through the recovery wells toward the recovery gallery.

25 Claims, 11 Drawing Figures



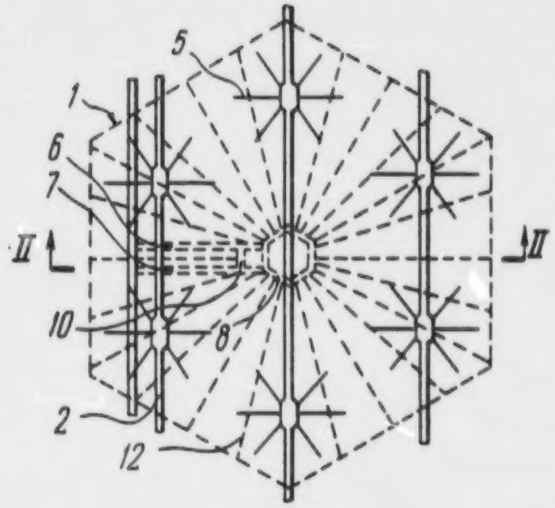

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FIG.1

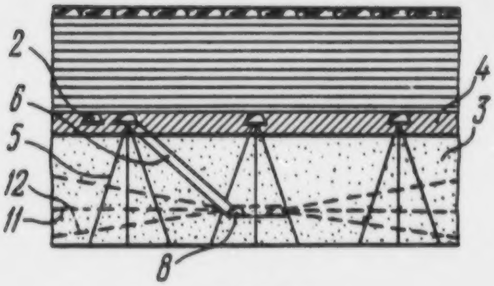
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FIG.2

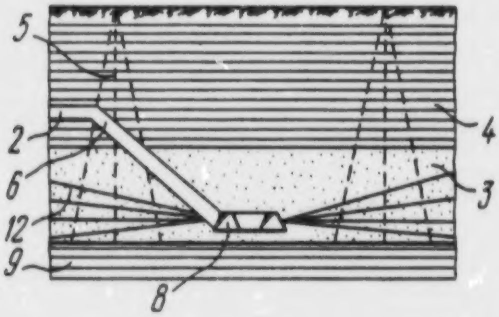

FIG.3

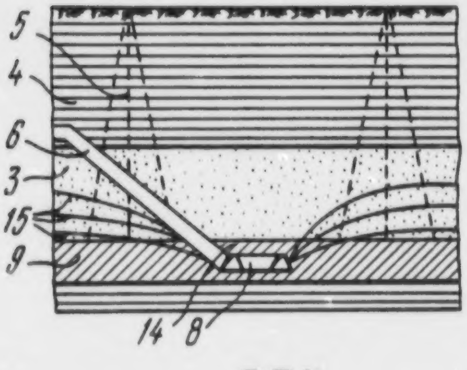
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FIG.4

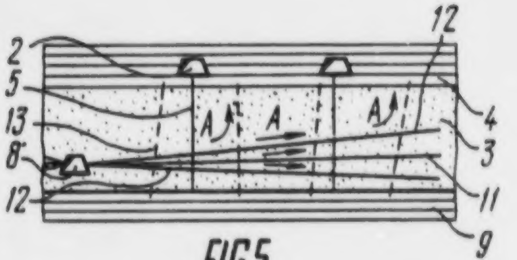
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FIG.5

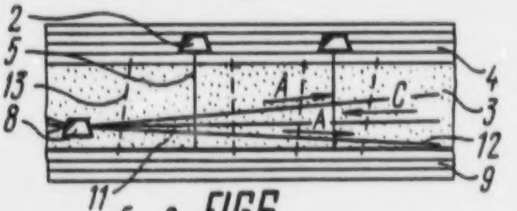
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FIG.6

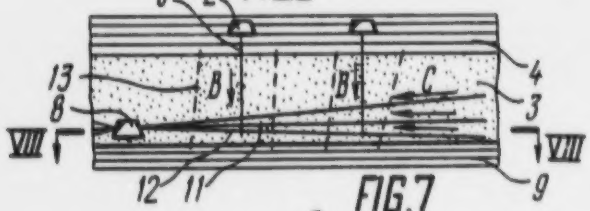
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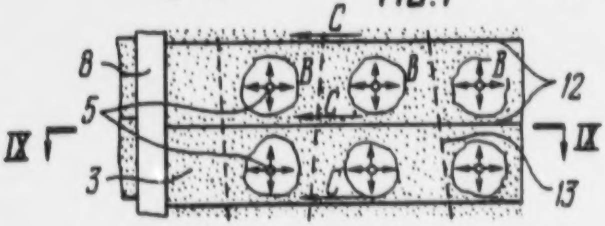
FIG.7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13

FIG.8

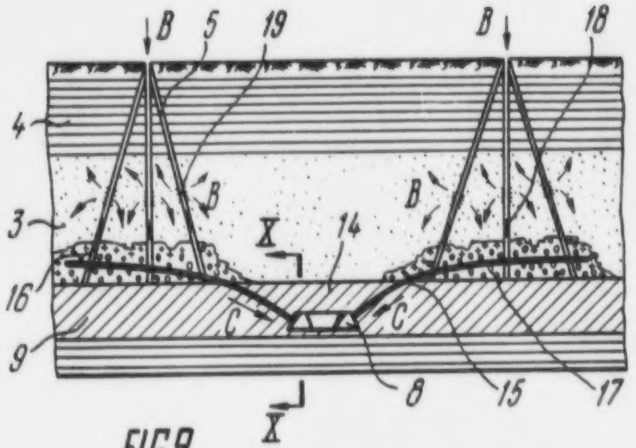
B
5
19
B
18
4
3
B
B
X
14
16
C
C
9
8
15
17
X

FIG.9

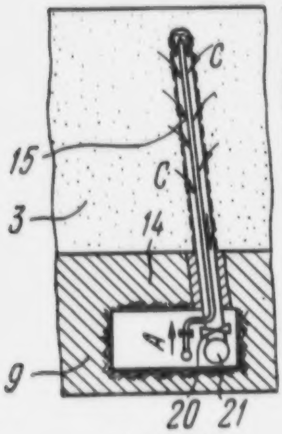
C
15
C
3
14
A
9
20
21

FIG.10

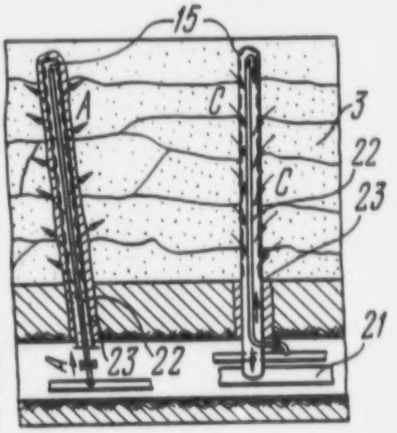
15
A
C
3
22
C
23
21
A
23
22

FIG.11

METHOD OF THERMAL-MINE RECOVERY OF OIL AND FLUENT BITUMENS

The invention relates to recovering oil from highly viscous oil-bearing formations, and, more particularly, it relates to a method of thermal-mine recovery of oil and fluent bitumens or kerogens.

The invention can be utilized to utmost effectiveness for recovering oil from fissured and incoherent oil-bearing strata.

The invention can be also utilized for recovering oil from exhausted oil-bearing strata.

At present, oil-bearing formations of the abovementioned kinds cannot be developed by the conventional technique of drilling boreholes and wells from the ground surface, on account of the oil yield being in such cases too small for practical purposes.

There is known a method of mining recovery of highly viscous oil from oil-bearing formations or beds, according to which oil is removed to the ground surface together with the oil-bearing shale or rock. The method includes recovery of oil by providing subterranian mine workings within the oil-bearing formation, and subsequent imploding of these workings (see, for example, the U.S. Pat. No. 3,437,378; Cl. 299-2, filed Feb. 02, 1967, dated Apr. 08, 1969).

This known method, however, is labour-consuming and costly.

Besides, it involves definite hazards connected with the subsequent imploding of the mine workings.

In addition to that, the method affects the working environment and safety of the personnel, because when oil is removed together with the rock or shale containing it, as the mine workings are being excavated, gases and oil issue from the oil-bearing formation into these workings; furthermore, when oil is recovered from an incoherent oil-bearing bed, spontaneous caving-in of the workings might occur.

There is further known a mining method of recovering oil from oil-bearing beds, according to which mine workings are provided in impermeable rock underlying the oil-bearing formation, and series of wells are drilled therefrom. Then high-velocity whirling jets of liquid are directed through these wells into the oil-bearing bed, to form a slurry which is withdrawn from the bed (see the U.S. Pat. No. 3,934,935; Cl. 299-2, dated Jan. 27, 1976).

However, this method, too, is excessively labour-consuming and costly. Furthermore, it is significantly complicated in its implementation, on account of the great quantities of sand washed away with the oil from the oil-bearing bed.

There is known still another method of mining recovery of oil from an oil-bearing bed, without removing the rock or shale containing oil to the ground surface (see article by V.P. Tabakov "On Influence of Well Network Density upon Oil Yield, as Illustrated by Yarega Field Experience"/in Russian/, in Scientific-Engineering Manual on Oil Production, No. 41, VNIINeft, "NEDRA" Publishers, Moscow, 1971, p. 155).

The method includes providing a system of mine workings above the oil-bearing bed. The mining field is divided into a plurality of levels. Longitudinal field drifts are provided intermediate the levels, and drilling chambers are made therein. From these drilling chambers inclined and vertical wells are drilled into the oil-bearing bed, down to the bottom of the bed. The wells are uniformly spaced throughout the oil-bearing bed.

The spacing of the well faces, the number of the wells and the pattern of the mine workings may vary as this method is implemented, depending on the properties of the oil-bearing bed, its thickness and physical-chemical properties of the oil.

The structure of the wells requires their provision with casing columns, the voids between the casing pipes and the well wall at the well mouth being sealed with a cementing composition. The well faces remain open. A lift pipe string is lowered into the casing column, and ditches are made at the well mouths along the mine workings with an appropriate sloping angle for exposed free gravity flow of oil from the wells toward collection tanks.

At the initial stage of the operation of the wells oil, as a rule, gushes therefrom, and when the gushing dies away, air is pumped into the space between the casing and the lift pipes.

To provide for better gravity flow of oil, water is supplied into the ditches of the mine workings. Oil collected in the tanks is separated from water, heated up and pumped to the ground surface.

However, experience shows that when the last-described method is implemented in oil-bearing beds with highly viscous oil, the yield is too low.

Furthermore, the implementation of this method involves a great volume of mining work and drilling a great amount of wells uniformly spaced throughout the oil-bearing formation.

The above-mentioned method requires higher costs for lifting oil after its gushing is stopped.

Besides, the great number of operating wells uniformly spaced throughout the oil-bearing formation complicates the monitoring of the performance of individual wells, their maintenance and repairs.

The abovediscussed difficulties have brought about the need for developing oil recovery methods based on exerting physical-chemical action on the oil-bearing bed itself, and on the fluid saturating this bed.

There is further known a thermal-mine method of oil recovery by exerting steam and heat action upon an oil-bearing bed (see article by L.M. Rusin "Experience in Pumping Steam into Fissured-Porous Bed of Yarega Field"/in Russian/, in the already mentioned Scientific-Engineering Manual on Oil Production, No. 41, VNIINeft, "NEDRA" Publishers, Moscow, 1971, p. 109).

The method includes providing a system of mine workings above an oil-bearing bed.

Vertical and inclined wells are drilled from these mine workings. Pipelines are constructed in these above-bed mine workings for the heat-carrier supply, and some of the wells are connected thereto. These wells are operated as injection ones, through which the heat carrier, e.g. steam is injected or charged into the oil-bearing bed to heat the bed and to force oil into the rest of the wells, operated as recovery ones. The injection and recovery wells are alternated and spaced uniformly throughout the oil-bearing formation. The mouths of the recovery wells are open, for free gravity flow of oil down the inclined ditches of the mine workings toward collecting tanks. The mouths of both injection and recovery wells are provided with gate means.

At the initial period of the operation, with the oil-bearing bed being heated up with the heat-carrier, oil gushes from the wells, and when the gushing dies away, air is pumped into the space between the casing and the lift pipes to recover oil through the wells.

However, this known method requires the drilling of a great amount of wells, since a single well is insufficient either to heat up the oil-bearing bed or to recover oil therefrom, particularly, if the bed is relatively thin.

Furthermore, the method involves additional costs connected with supplying compressed air to lift oil through the wells.

Moreover, with the same mine workings housing both heat-carrier injection wells and oil recovery wells, the temperature and gas-content conditions of the whole atmosphere in the mine are affected; the working environment and safety of the personnel are impaired.

Besides, there is an eventuality of the heat-carrier finding its way and bursting into the open recovery wells. Such breakthrough of the heat-carrier into ventilated mine workings significantly steps up the consumption of the heat carrier per one weight unit of recovered oil.

Breaks in the operation of the recovery and injection wells result in sand plugs forming therein, and lead to a considerable amount of downtime of the wells for maintenance and repair work, which affects the per day rate of the oil yield of the oil-bearing formation.

There is also known a thermal-mine method of oil recovery, wherein a system of mine workings is provided above the oil-bearing bed, inclined at an angle from 1° to 3° to a horizontal plane (see, for example, the SU Inventor's Certificate No. 446,631).

From these mine workings injection wells are drilled for charging the heat-carrier and its uniform propagation through the oil-bearing bed. A slope and a man way are provided into the lower part of the oil-bearing bed, and a recovery gallery is provided in this part of the bed.

From the recovery gallery a system of horizontal and inclined oil recovery wells is drilled. The heat-carrier is charged into the said injection wells for its uniform propagation throughout the oil-bearing bed and for forcing oil into the said horizontal and inclined recovery wells, toward the said recovery gallery from which oil is withdrawn to the ground surface.

However, the implementation of this method involves the drilling of a great number of injection wells, to provide for uniform distribution of the heat-carrier through the oil-bearing bed, since a single heat-carrier injection well is by far insufficient for taking care of the whole oil-bearing bed, particularly when the latter is relatively thin.

Furthermore, with a smaller number of injection wells the rate of heating of the oil-bearing bed is low, whereby the yield is likewise low, which considerably increases the time of developing the oil-bearing formation.

Moreover, non-homogeneity of the oil-bearing bed and the fact that in most cases the bed has fissures therein would not enable to conduct in the most efficient manner the forcing of oil by the heat-carrier into the horizontal and inclined recovery wells, toward the recovery gallery, on account of the dominating infiltration and propagation of the forcing-out fluid through these fissures and the highly permeable zones of the oil-bearing bed, which also affects the oil yield and prolongs the development of the oil-bearing formation.

Besides, the per day yield of the oil-bearing bed is affected by the fact that the heat-carrier is charged through the injection wells, while the near-face areas of the recovery wells are less heated, and it is here where the oil flow meets the strongest resistance to its progress.

In addition to that, the charging of the heat carrier into the injection wells drilled from the mine workings overlying the oil-bearing bed results in eventual breakthrough of the heat-carrier into the inclined and horizontal recovery wells and into the recovery gallery, which sharply decreases the rate of heating the oil-bearing bed, increases the consumption of the heat-carrier, affects the working environment and safety of the personnel.

Apart from that, the supply of the heat-carrier into the great number of the required injection wells drilled from the mine workings overlying the oil-bearing bed, for uniform propagation of the heat-carrier throughout the bed, steps up the cost of ventilation of the mining workings, on account of a high degree of dissipation of heat into these workings.

It is the main object of the present invention to provide a method of thermal-mine recovery of oil, which should enable to increase the per day and total yield of an oil-bearing bed and to cut down the time of its development.

It is a not less important object of the present invention to provide a method of thermal-mine recovery of oil, which should enable to reduce the cost of recovering oil from an oil-bearing bed, to reduce the number of the wells required for charging the heat-carrier and withdrawing oil, and to minimize the complications associated with preparing the oil bed for development and with recovering the oil, on account of great quantities of sand evolving from this oil-bearing bed.

It is still another object of the present invention to provide a method of thermal-mine recovery of oil, which should enable to cut down the cost of ventilation of the mine workings required for maintaining the necessary gas-content and temperature characteristics of the atmosphere in the mine, to enhance the working environment and safety of the personnel.

These and other objects are attained by the creation of the method of thermal-mine recovery of oil, including: providing a system of mine working above an oil-bearing formation or bed; drilling from these mine workings and/or from the ground surface a plurality of injection wells for charging a fluid into the oil-bearing bed; providing a slope and a man way in the area of the oil-bearing bed; providing a recovery gallery in this area of the oil-bearing bed; drilling from the recovery gallery a system of horizontal and inclined recovery wells for recovering oil; charging a heat-carrier into the oil-bearing bed for heating same to a temperature whereat oil attains sufficient fluidity within the oil-bearing bed; charging a pressurized fluid into the oil-bearing bed to force oil from the oil-bearing bed into the horizontal and inclined recovery wells toward the recovery gallery; and withdrawing oil from the recovery gallery to the ground surface, in which method, in accordance with the invention, the heat-carrier is charged into the oil-bearing bed through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing bed, and, following the heating of the oil-bearing bed to the required temperature, the heat-carrier supply to the recovery wells is terminated, and the pressurized fluid is charged into the injection wells minimally associated with the highly permeable zones of the oil-bearing bed, to force oil from the oil-bearing bed into the horizontal and inclined recovery wells toward the recovery gallery.

The method enables to increase the yield of the oil-bearing bed and to cut down the period of its development, owing to the enhanced penetration of the heat-carrier into the oil-bearing bed and to the stepped-up rate of the heating of the oil-bearing bed through the latter's greater volume, as well as to reduce the resistance to the oil flow encountered at the near-face areas of the recovery wells and in the highly permeable zones of the oil-bearing bed, connected therewith, at the infiltration of oil therein; the method further expanding the borders of the process of forcing oil from the oil-bearing bed.

The method enables to cut down the costs of recovering oil from an oil-bearing bed, owing to the improved pattern of the layout of the recovery wells throughout the bed, extending as they do across the direction of the highly-permeable zones of the bed, and also owing to the better yield of these wells and the possibility of reducing their number, as well as the number of the mine workings which have to be provided to drill the recovery wells therefrom.

The operating costs of the well system are reduced by the lesser number of the recovery wells required, by the reduced ingress of sand from the oil-bearing bed into the recovery wells and by the minimized eventuality of sand plugs forming therein and involving additional efforts of eliminating these plugs.

The method further enables to cut down the cost of ventilating the mine workings, in order to maintain therein acceptable atmospheric conditions, and to enhance the working environment and safety of the personnel, owing to the reduced number of ventilated mine workings.

It is expedient that the recovery gallery should be provided in the lower part of the oil-bearing bed.

This would enable to utilize in the fullest degree both the phenomenon of forcing-out the oil with the pressurized fluid, and the phenomenon of gravity flow of oil into the recovery wells.

Alternatively, when oil is recovered from an incoherent oil-bearing formation, particularly, one decreasing its stability upon being heated, it may be preferable that the recovery gallery should be provided below the oil-bearing bed, so that it should be separated from the bed by a low-permeability stable interbed of rock.

This would enable, when recovering oil from an incoherent oil-bearing bed, to reduce the cost of providing mine workings, by making them in rock more suitable for the purpose, and also to reduce the undesirable propagation of heat from the oil-bearing bed into the mine workings.

It is also expedient that the heat-carrier should be charged into the oil-bearing bed through the horizontal and inclined recovery wells to heat the oil-bearing bed until the latter is heated up to a temperature above which the viscosity of the oil at further heating is reduced but insignificantly.

This would enable to reduce the consumption of the heat-carrier by the oil recovery process and to enhance the quality of the atmosphere in the mine.

It is further expedient, if the injection wells penetrate the highly permeable zones of the oil-bearing bed, prior to charging the fluid into the injection wells, to fill the highly-permeable zones of the oil-bearing bed communicating with these wells with a plugging composition

retaining oil-permeability of the porous body of the oil-bearing bed.

This enables to enhance the homogeneity of the oil-bearing bed, to conduct the forcing-out of oil by the fluid in an efficient way and to increase the yield of the oil-bearing bed.

It may be also expedient, if one and the same recovery gallery has some of the recovery wells penetrating the highly permeable zones of the oil-bearing bed and other recovery wells not communicating with these highly permeable zones, to perform, simultaneously with the charging of the heat-carrier into the oil-bearing bed through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing bed, recovering of oil through those of the horizontal and inclined recovery wells which have the minimum communication with the highly permeable zones of the oil-bearing bed.

This enables to recover oil simultaneously with the heating of the oil-bearing bed and to accelerate the heating of the oil-heating bed itself with partial heating and creating improved conditions for the propagation of the heat-carrier into the porosity space of the oil-bearing bed.

It is further expedient that at a later stage of the oil recovery from the oil-bearing bed the recovery gallery should be periodically filled with a fluid of a density in excess of that of the oil.

This enables to increase the total yield of the oilbearing bed, by creating a non-stationary duty of the performance of the bed, the variation of the direction of infiltration flows in the bed and its better capillary impregnation.

Furthermore, it enables to reduce the degree of breakthrough of the heat-carrier into the recovery gallery, and thus to improve the working environment and to reduce the ventilation costs.

It is expedient, in the case of an incoherent oil-bearing bed, with the recovery gallery having been provided under the bed, prior to the charging of the fluid into this incoherent oil-bearing bed, to wash out with a liquid through the injection wells an area in the lower part of the bed, and then to supply into this area materials forming a stable strong structure permeable for the oil, and to drill ascending recovery wells into this area.

This enables to bring down the cost of drilling ascending recovery wells in an incoherent oil-bearing bed which is unstable during the heating and under the action of a flushing liquid, to reduce the ingress of big quantities of sand into the ascending recovery wells and into the recovery gallery, and to operate these wells efficiently and without undue complications.

It is likewise expedient, in the case of consolidation of the lower part of the oil-bearing bed through the injection wells drilled from the ground surface, to provide the recovery gallery below this oil-bearing bed and to drill therefrom ascending recovery wells into the consolidated area of the oil-bearing bed, and also to seal the faces of the injection wells and to charge the fluid through the injection wells into the area of the oil-bearing bed, disposed above the consolidated area of the bed, so as to force oil from the oil-bearing bed into the ascending recovery wells toward the recovery gallery.

This enables to use in the most efficient way the phenomenon of forcing oil by the fluid in combination with the gravity flow of oil, to minimize the possibility of the fluid breaking through directly into the ascending recovery wells drilled from the recovery gallery underlying the oil-bearing bed and to reduce the ingress of sand into the ascending recovery wells.

It is further expedient, if the fluid infiltrates into the ascending recovery wells, to close periodically the ascending recovery wells simultaneously with the feeding of the fluid into the injection wells, and, following this closing, to withdraw oil from the area underlying the closing points.

This enables to step up the oil yield of the oil-bearing bed, on account of periodic enforced fluid recovery, creating non-stationary mode of its performance, with periodic withdrawal of oil and cleaning of the near-face areas of the ascending recovery wells, and also to control the propagation of the heat-carrier through the oil-bearing bed, for the latter to be heated evenly throughout its volume.

The invention will be further described in connection with an embodiment thereof, with reference being made to the appended drawings, wherein:

FIG. 1 is a plan view of a system of developing a single mining element or block of an oil-bearing bed, with mine workings and wells indicated;

FIG. 2 is a sectional view taken on line II—II of FIG. 1;

FIG. 3 is a sectional view of a single mining block of the oil-bearing bed, with mine workings and wells drilled from the mine workings within the oil-bearing bed and from the ground surface;

FIG. 4 is a sectional view of a single mining block of the oil-bearing bed, with the mine workings therein and wells drilled from the mine workings below the oil-bearing bed and from the ground surface;

FIG. 5 is a sectional view of a single mining block of a fissured oil-bearing bed being heated;

FIG. 6 is a sectional view of a single mining block of a fissured oil-bearing bed being heated, with simultaneous recovery of oil;

FIG. 7 is a sectional view of a single mining block of a fissured oil-bearing bed during the oil recovery stage;

FIG. 8 is a view in plan of the section of FIG. 7 along line VIII—VIII;

FIG. 9 is a sectional view of a single mining block of an oil-bearing bed, with the mine workings therein and wells drilled from the mine workings underlying the oil-bearing bed and from the ground surface;

FIG. 10 is a sectional view taken on line X—X of FIG. 9 of a portion of a single mining block of an oil-bearing bed, with the mine workings underlying the oil-bearing bed and wells drilled therefrom;

FIG. 11 is a sectional view of a portion of a single mining block, with the mine workings underlying the oil-bearing bed and wells drilled therefrom.

The herein disclosed method is preferably performed, as follows.

The entire oil-bearing formation or bed is subdivided into a plurality of mining elements or blocks 1 (FIG. 1).

A system of mine workings 2 is provided above the oil-bearing formation or bed 3 (FIG. 2) in low-permeability above-bed rock 4.

Then from these mine workings 2 there are drilled vertical and inclined injection wells 5 for charging a fluid into the oil-bearing bed 3. If practical, e.g. in case of shallowly extending oil-bearing beds 3, the vertical and inclined injection wells 5 are drilled from the ground surface. Then a slope 6 and a man way 7 (FIG. 1) are provided into the oil-bearing bed 3, and a recovery gallery 8 is excavated within the oil-bearing bed 3.

The slope 6 and the man way 7 (FIG. 1) are descending mine workings extending toward the area of the oil-bearing bed 3 (FIG. 2) and necessary for the provision of the recovery gallery 8. Alternatively, the slope 6 and the man way 7 (FIG. 1) may be vertical. Here and in the disclosure to follow the expression "the area of the oil-bearing bed" is used to describe the oil-bearing bed 3 per se and the under-bed rock 9 (FIG. 3) adjoining the bed.

Provided intermediate the slope 6 and the man way 7 (FIG. 1) is a pumping chamber 10 to accommodate pumps operable to raise oil to the ground surface. The recovery gallery 8 is used to drill therefrom horizontal recovery wells 11 (FIG. 2) and inclined recovery wells 12.

The term "inclined wells 12", as used here, is meant to describe both ascending and descending wells.

While providing the mine workings 2 above the oil-bearing bed, the slope 6, the man way 7 (FIG. 1) and the recovery gallery (FIG. 2), and while drilling the injection wells 5 and the recovery wells 11, 12, there is conducted a structural analysis of the geological formation of the oil-bearing bed 3, and there is determined the direction of the highly permeable zones of this oil-bearing bed; there is also investigated the relationship between these zones and the injection wells 5, and the recovery wells 11 and 12.

The expression "highly permeable zones of the oil-bearing bed 3" is used here to describe oriented abnormally permeable zones in the porous body of the oil-bearing bed 3, i.e. those zones of the oil-bearing bed of which the permeability is several times that of the main body of the oil-bearing bed, as well as fissures 13 (FIG. 5).

In case of an absence in the oil-bearing bed 3 of a system of natural fissures 13, or else of abnormally permeable zones in the porous body of the oil-bearing bed 3, man-made fissures are provided therein, e.g. by conducting hydraulic fracturing of the oil-bearing bed 3, e.g. by charging through the recovery wells 11 and 12 a liquid with a breakdown agent, under a pressure in excess of the rock pressure.

Following the preparation of the oil-bearing bed for the development, a heat-carrier, e.g. steam is fed through a system of pipelines into the horizontal recovery wells 11 and inclined wells 12 extending substantially across the dominating direction of the highly permeable zones, e.g. fissures 13 of the oil-bearing bed, to heat the latter to a temperature whereat oil acquires sufficient fluidity within the oil-bearing bed 3. Instead of steam the heat-carrier may be in the form of warm or hot water, as well as of steam-water mixtures with surface-active agents or gases. Arrows "A" in the drawings indicate the direction of propagation of the heat-carrier through the oil-bearing bed.

As a result of the heat-carrier being charged into the horizontal recovery wells 11 and inclined recovery wells 12 extending across the dominating direction of the highly permeable zones, e.g. of the main pattern of the fissures 13 of the oil-bearing bed 3, the heat-carrier uniformly and swiftly propagates throughout the body of the oil-bearing bed 3. Thus, to heat up the oil-bearing bed 3, there is utilized the maximum available surface of the recovery wells 11, 12 and of the fissures 13 of the oil-bearing bed 3, which is of a particular importance at the initial stage of the development of the oil-bearing bed, when the viscous low-fluent oil opposes the access of the heat-carrier into the porous body of the oil-bearing bed, and the heat transfer to the oil-bearing bed can be effected practically exclusively owing to its heat conductivity. This enhances the optimum impact of the action of the heat-carrier upon the oil-bearing bed 3, speeds up the heating-up of this oil-bearing bed 3 and rapidly reduces the viscosity of oil, so that the latter attains sufficient fluidity in the porous body of the oil-bearing bed 3, which cuts down the oil field development time.

The greater surface of the opening-up of the oil-bearing bed 3 by the recovery wells 11 and 12 and by the fissures 13 associated and communicating therewith enables to reduce significantly the number of the wells required for oil recovery, and thus to save the cost of drilling and operating these wells.

This also cuts down the volume of the mining work associated with the provision of the mine workings, such as the slope 6 (FIG. 1), man way 7 and recovery gallery 8 required for drilling the recovery wells 11 (FIG. 2) and 12.

The greater surface area of the opening-up of the oil-bearing bed 3 also eliminates the necessity of charging the heat-carrier into the formation under a very high pressure, which helps prevent breakthrough of the heat-carrier into the mine workings 2 overlying the oil-bearing bed, into the slope 6 (FIG. 1), man way 7 and recovery gallery 8 (FIG. 2) and its bleeding beyond the area of the portion of the oil-bearing bed 3, which is being developed; and which also improves the working environment in the mine workings and enhances safe working conditions. The consumption of the heat-carrier is reduced, too.

The heating of the oil-bearing bed 3 from the recovery wells 11 and 12 enables to bring down considerably the infiltration resistance to the flow of oil from the oil-bearing bed 3 into the fissures 13 (FIG. 5) and the recovery wells 11 and 12.

This fact, in its turn, enables to increase significantly the per day yield of the oil-bearing bed, as well as to prevent the ingress of great quantities of sand into the recovery wells 11 and 12, and thus to preclude eventual faults in the operation of these wells.

Upon the oil-bearing bed 3 having been heated up to a temperature whereat the oil acquires sufficient fluidity within the oil-bearing bed 3, the feed of the heat-carrier into the recovery wells 11 and 12 is discontinued.

Then a pressurized fluid, e.g. warm water is charged into the injection wells 5 which are minimally associated with the highly permeable zones, e.g. fissures of the oil-bearing bed 3, to force oil from this oil-bearing bed 3 into the horizontal recovery wells 11 and inclined recovery wells 12 toward the gallery 8.

The direction of propagation of the fluid through the oil-bearing bed 3 is indicated in the drawings with arrows "B" (FIGS. 7 and 8).

The direction of the flow of oil forced from the oil-bearing bed 3 is indicated in the drawings with arrows "C".

From the recovery gallery 8 oil is lifted to the ground surface by pumps installed in the pumping chamber 10 (FIG. 1).

The charging of the fluid through the injection wells 5 (FIGS. 7 and 8) minimally associated with the fissures 13 enhances the efficiency of the forcing of oil from the oil-bearing bed into the recovery wells 11 and 12 (FIG. 7) and steps up the oil yield of the oil-bearing bed 3.

This also enables to minimize the eventuality of the fluid breaking through into the recovery wells 11 and 12, as well as to reduce the amount of the fluid required for forcing oil from the oil-bearing bed 3. The conditions for the ingress of sand from the oil-bearing bed 3 into the recovery wells 11 and 12 are likewise impaired, thus eliminating eventual faults in the performance of these wells.

With oil being forced from the oil-bearing bed by the fluid into the horizontal recovery wells 11 and inclined recovery wells 12 of which the infiltration area is more heated than the rest of the zones of the formation, so that oil therein has the lowest viscosity, the oil yield of the oil-bearing bed 3 is stepped up, and the productivity of the recovery wells 11 and 12 is maintained at the maximum.

The utilization of the horizontal recovery wells 11 and inclined recovery wells 12 opening up to the maximum the highly permeable zones, e.g. fissures 13 of the oil-bearing bed for charging the heat-carrier therethrough at the bed-heating stage, and, following the heating up of the oil-bearing bed 3, for collecting therein the oil forced by the fluid charged into the injection wells 5 saves the cost of drilling extra wells and providing either extra or greater mine workings, such as the slope 6 (FIG. 1), man way 7 and recovery gallery 8; it further saves ventilation costs associated with ventilation of greater mine workings, and cuts down the time of the development of the oil-bearing bed 3 (FIG. 7).

To utilize to the fullest possible degree the phenomenon of gravity flow of oil for oil recovery into the recovery wells 11 and 12, simultaneously with the forcing of oil by the fluid into the same wells 11 and 12, in one embodiment of the present invention the slope 6 and the man way 7 (FIG. 1) are provided into the lower part of the oil-bearing bed 3 (FIG. 3), and then there is provided in this lower part of the oil-bearing bed 3 the recovery gallery 8 from which the horizontal recovery wells 11 and the inclined recovery wells 12 are drilled.

This enables to step up the productivity of the recovery wells 11 and 12 and to increase the per day yield of the oil-bearing bed 3.

In another embodiment of the invention, in the case of recovering oil from an incoherent oil-bearing bed 3 becoming unstable when heated, the slope 6 and the man way 7 (FIG. 1) are provided into low-permeability stable rock 9 underlying the oil-bearing bed 3.

Then the recovery gallery 8 is provided so that it is separated from the incoherent oil-bearing bed 3 by a low-permeability steady interbed 14 (FIG. 4) of the rock 9. Then ascending recovery wells 15 are drilled from this recovery gallery.

In this case the cost of the provision of the recovery gallery 8 is reduced, the undesirable propagation of heat from the oil-bearing bed 3 into this recovery gallery 8 being curbed down, and the ventilation costs being reduced, too.

In a preferred embodiment of the present invention, the heat-carrier is fed into the oil-bearing bed 3 through the recovery wells 11, 12 and 15 until the oil-bearing bed 3 is heated up to a temperature above which the viscosity of the oil is practically not reduced by further heating.

The practical experience of the inventors has proved that various crude oil grades with different compositions have each a definite temperature above which this oil grade does not become more fluid at further heating.

If the oil-bearing bed 3 is inadequately heated, i.e. if it is not heated to reduce the oil viscosity to the necessary level, the efficiency of the forcing out of oil by the pressurized fluid is affected; however, on the other hand, excessive heating of the oil-bearing bed 3 would not significantly enhance this efficiency and increase the oil yield.

The heating of the oil-bearing bed 3 to the abovementioned optimum temperature reduces the overall consumption of the heat-carrier by the oil recovery process. In this way excessive heating of the oil-bearing bed 3 is precluded, the atmosphere in the mine workings is improved, and the costs of ventilation of the mine workings 2 (FIG. 1) above the oil-bearing bed 3, of the slope 6 and of the man way 8 are reduced.

In another embodiment of the present invention, in the case of the presence in the oil-bearing bed (FIG. 5) of a dense network of natural high-permeability zones, e.g. fissures 13, the injection wells 5 drilled from the mine workings 2 and from the ground surface inadvertently penetrate or open up at least some of these fissures 13.

Therefore, prior to forcing oil by the pressurized fluid into the recovery wells 11, 12 and 15 (FIG. 4) toward the recovery gallery 8, there is charged into those of the injection wells 5 (FIG. 5), which are communicating with the fissures 13, a plugging composition selected to retain the oil-permeability of the porous body of the oil-bearing bed, e.g. a binder based on a mixture of phenols with water, a solvent and a setting agent.

Then into the same injection wells 5 there is charged a neutral liquid, e.g. crude oil, to force the plugging solution from these injection wells 5 into the fissures 13 of the oil-bearing bed 3.

And only then the pressurized fluid is charged into the injection wells 5 to force oil from the oil-bearing bed 3 into the recovery wells 11, 12 and 15 (FIG. 4), toward the recovery gallery 8.

The filling up of the fissures 13 (FIG. 5) associated with at least some of the injection wells 5 with the plugging solution enables to level out the homogeneity of the oil-bearing bed 3 as far as its oil-permeability is concerned, and to enhance the efficiency of the forcing-out of oil from this oil-bearing bed 3 by the pressurized fluid. This enables to increase the oil yield of the oil-bearing bed 3, to prevent breakthrough of the pressurized fluid via the fissures 13 into the recovery wells 11, 12 and 15, and to reduce the amount of the pressurized fluid required for forcing out oil.

In another embodiment of the invention, in a case when the amount of the fissures 13 in the oil-bearing bed 3 is relatively small, and some of the recovery wells 11, 12 and 15 (FIG. 4) do not penetrate these fissures 13 (FIG. 5) of the oil-bearing bed 3, the heat-carrier is charged into the recovery wells 11, 12 and 15 extending across the direction of the main system of the fissures 13, and simultaneously oil is collected from the oil-bearing bed 3 through those of the recovery wells 11, 12 and 15 which have the minimum degree of communication or association with the fissures 13 (FIG. 6).

This enables to recover oil simultaneously with the heating of the oil-bearing bed 3, to relieve partly the porous space of the oil-bearing bed 3 from oil, thus offering this space for better propagation of the heat-carrier thereinto and to speed up the heating of the oil-bearing bed 3, owing to the greater area of the contact of the heat-carrier with the oil-bearing bed 3.

Following the heating up of the oil-bearing bed to the predetermined temperature, the feed of the heat-carrier into the recovery wells 11 and 12 is discontinued, and the pressurized fluid is charged into the injection wells 5 to force oil from the oil-bearing bed 3 into the recovery wells 11 and 12, toward the recovery gallery 8.

However, in certain practical cases, at a later stage of the oil production process the oil-bearing bed 3 becomes partly exhausted, and the productivity of the recovery wells 11 and 12 becomes insufficient.

In this case the recovery gallery 8 (FIGS. 2 and 3) provided within the oil-bearing bed 3 is preferably filled with a fluid having a density in excess of that of oil, e.g. with warm water.

Then a heat carrier under a relatively high pressure, e.g. steam is charged as the pressurized fluid into those of the injection wells 5, which have the minimum communication or association with the fissures 13.

This feed of the heat-carrier into the oil-bearing bed 3 is carried out until the latter is heated to a predetermined higher temperature.

Then the charging of the heat-carrier into the said injection wells 5 is terminated, warm water is charged thereinto as the pressurized fluid, and from the recovery gallery 8 the fluid, e.g. water is pumped by pumps installed in the pumping chamber 10 (FIG. 1) into the mine workings 2 (FIG. 2) overlying the oil-bearing bed 3 and/or to the ground surface, to charge this fluid once again into the said injection wells 5.

Following the pumping out of water from the recovery gallery 8, the operation of forcing out oil from the oil-bearing bed 3 by the pressurized fluid into the recovery wells 11 and 12 toward the recovery gallery 8 is continued as long as the productivity of these wells 11 and 12 remains at a satisfactory level.

Upon the reduction of the productivity of the recovery wells 11 and 12 below the said level, the recovery gallery 8 is once again filled with warm water, and the heat-carrier is charged into the injection wells 5.

The abovedescribed pattern of filling the recovery gallery 8 with water and pumping water therefrom is repeated periodically, as long as the oil-bearing bed 3 remains adequately heated, and the productivity of the recovery wells 11 and 12 remains at the satisfactory level.

The recurrent filling of the recovery gallery 8 with the fluid, e.g. water enables to charge the heat-carrier at a high pressure through the injection wells 5, and thus to increase the rate and to enhance the efficiency of the heating-up of the oil-bearing bed 3 and of the forcing-out of oil therefrom, while reliably sealing away the recovery wells 11 and 12 and precluding the breakthrough of the heat-carrier, e.g. condensed steam into the recovery gallery 8 and into the mine workings 2 overlying the oil-bearing bed 3, including the slope 6 and the man way 7 (FIG. 1 In this way the costs of ventilation of the said mine workings are substantially reduced, and the working environment and safety of the personnel are enhanced.

The filling up of the recovery gallery 8 (FIG. 2) extending within the oil-bearing bed 3 with the fluid, e.g. water provides for a substantial increase in the water-saturation of the oil-bearing bed 3, owing to the water inflow through the recovery wells 11 and 12 and the fissures 13 associated therewith, and for more intense capillary impregnation of the oil-bearing bed 3, while the pumping out of this fluid from the recovery gallery 8 provides for enforced recovery of liquid from the oil-bearing bed 3.

In this manner a non-stationary mode of performance of the oil-bearing bed 3 is provided for, with recurrent oscillations of the liquid flow rates and variation of the velocity and direction of the infiltration flows, which enables to involve into the development by the recovery wells 11 and 12 of low-permeability intervening portions of the bed 3, its blind portions, the least heated portions, and the like.

The abovedescribed processes increase the productivity of the recovery wells and cut down the time of the total oil production from the oil-bearing bed 3.

In another embodiment of the present invention, when oil is to be recovered from an incoherent oil-bearing bed 3 (FIG. 9), particularly a bed that becomes unstable upon being heated, following the drilling from either the mine workings 2 or from the ground surface of the injection wells 5 into the oil-bearing bed 3 to the bottom thereof, the slope 6 and the man way 7 are excavated into the low-permeability rock formation 9 underlying the oil-bearing bed 3.

Then the recovery gallery 8 is provided under the oil-bearing bed 3 so that it is separated from the latter by a low-permeability stable interbed 14 of the rock 9.

Following this, the casings of the injection wells 5 are perforated at points 16 within the lower part of the oil-bearing bed, and through the perforations there is charged into this incoherent oil-bearing bed 3 under a hydraulic fracturing pressure, i.e. a pressure in excess of the rock pressure, a cold liquid, e.g. water containing an expanding agent, e.g. sand.

Following the hydraulic fracturing of the oil-bearing bed 3 between the injection wells 5, cold liquid is pumped through the latter to wash away an area in the lower part of the oil-bearing bed 3.

Then materials are fed into this washed-away part of the oil-bearing bed, e.g. a binding agent based on a mixture of phenols with water, a solvent and a setting agent, to form a stable strong structure 17 of adequate oil permeability.

To enhance the permeability of this consolidated area, the binding or consolidating agent is preferably supplied into the washed away area of the oil-bearing bed together with granulated materials, and, also preferably, the binding or consolidating agent is forced through into the peripheral portions of the washed away area being consolidated by charging into the injection wells 5 a liquid which is neutral with respect of this agent, e.g. oil.

Following the consolidation of this area of the incoherent oil-bearing bed 3, ascending recovery wells 15 are drilled from the recovery gallery 8 into this consolidated area 17 of the oil-bearing bed 3.

Then the heat-carrier is charged through these recovery wells 15 into the oil-bearing bed 3 until at least the bottom part of the latter is heated up to a temperature whereat oil acquires the necessary fluidity within the oil-bearing bed 3.

With this attained, the charging of the heat-carrier through the recovery wells 15 is discontinued, and the pressurized fluid, e.g. steam is charged into the oil-bearing bed 3 through the injection wells 5 to force oil into the recovery wells 15 toward the recovery gallery 8.

The consolidation of the incoherent oil-bearing bed 3 through the injection wells 5 drilled either from the ground surface or from the mine workings 2 overlying the oil-bearing bed 3, and the subsequent drilling of the recovery wells 15 into the consolidated and adequately permeable area 17 enable to preclude complications otherwise associated with the drilling of the ascending recovery wells 15 in the incoherent oil-bearing bed 3, e.g. the inflow from the bed 3 of big quantities of sand on account of the action upon this bed 3 with the drilling tools and the drill mud. Thus, the cost of drilling the ascending recovery wells 15 is reduced.

Furthermore, the conditions of creating an infiltration zones of the ascending recovery wells 15 in the incoherent oil-bearing bed 3 are significantly facilitated, the complications involved in the creation of such zones are precluded, and conditions are created for supplying into the oil-bearing bed 3 greater volumes of the required filtration materials, including granulated materials.

There is provided a possibility of creating an infiltration zone of a great area adjacent to the ascending recovery wells 15 with the use of granulated materials, which enables to improve its permeability and to enhance the productivity of the recovery wells 15.

The complications associated with the operating of the ascending recovery wells are also minimized, owing to the minimized ingress of great quantities of sand from the incoherent oil-bearing bed 3 into these wells, which also increases the productivity of these wells 15.

The utilization of a large volume of granulated material for consolidation of the infiltration zone of the ascending recovery wells 15 in the lower portion of the incoherent oil-bearing bed 3 provides for better draining coverage by the recovery wells 15 of a greater area of the oil-bearing bed 3 and steps up the productivity of the wells.

Ultimately, this enables to reduce the volume and number of the mine workings which are to be provided, i.e. of the slope 6 (FIG. 1), of the man way 7 and of the recovery gallery or galleries 8, owing to the smaller number of the recovery wells (FIG. 9) required for the development of the oil-bearing bed 3.

In still another embodiment of the present invention, to enhance the efficiency of forcing out oil by the pressurized fluid into the recovery wells 15 toward the recovery gallery 8 and to utilize to the fullest degree the phenomenon of gravity flow of oil into the recovery wells 15, prior to charging the pressurized fluid into the injection wells 5 to force out oil from the incoherent oil-bearing bed 3, the faces of the injection wells 5 are sealed, e.g. with aid of packers 18. Then perforations 19 are made through the respective casings of the injection wells 5 centrally of the oil-bearing bed 3, and the heat-carrier is charged into the injection wells 5 as the pressurized fluid, e.g. steam, to force oil into the ascending recovery wells 15 toward the recovery gallery 8.

This enables to enhance the efficiency of the utilization of the pressurized fluid, e.g. steam as both the agent for forcing out oil and as the heat-carrier for heating the oil-bearing bed, and thus to reduce the consumption of this pressurized fluid.

The sealing of the faces of the injection wells 5 with the packers 18 and the charging of the pressurized fluid into the central part of the incoherent oil-bearing bed 3 prevents breakthrough of this fluid, e.g. of condensed steam, into the ascending recovery wells 15 and into the mine workings 2 overlying the oil-bearing bed 3, the slope 6, the man way 7 and the recovery gallery 8, which improves the state of the atmosphere in the mine and reduces the ventilation costs.

The charging of the pressurized fluid into the central part of the incoherent oil-bearing bed 3 also prevents the ingress of great quantities of sand into the ascending recovery wells 15.

As the pressurized fluid, e.g. steam is charged through the injection wells 5 into the incoherent oil-bearing bed 3 to force oil therefrom into the ascending recovery wells 15 toward the recovery gallery 8, the portion of the incoherent oil-bearing bed 3 intermediate the wells 5 and 15 is under the action of the most pronounced pressure drop (or, as it is sometimes said, under the greatest depression).

Oil within this portion of the oil-bearing bed 3 is under the most pronounced action of the pressurized fluid, e.g. of steam, and is the first to be forced out into the recovery wells 15, i.e. this portion is the first to become highly permeable for the pressurized fluid, e.g. steam.

Condensed steam becomes capable of breaking through into the ascending recovery wells 15, affecting thereby the state of the mine atmosphere and doing no useful work of forcing oil from the oil-bearing bed 3. Besides, the breakthrough of the pressurized fluid directly into the recovery wells 15 sharply increases the quantity of sand carried into these wells and clogs their infiltration zone with sand.

In this case, according to a further embodiment of the present invention, simultaneously with the charging of the pressurized fluid into the injection wells 5, the ascending recovery wells 15 (FIG. 10) are periodically closed off, e.g. with a gate 20. Following their closing-off, oil is pumped from a zone underlying the closing-off point, i.e. from the recovery well 15 below the gate 20, and from the oil-collecting manifold 21 through the recovery gallery 8 to the ground surface.

The period between the opening and closing of the recovery well 15, during which oil is recovered from the open well 15, is set to correspond to the satisfactory productivity of the well 15 and to the tolerable content of the fluid, e.g. of condensed steam in its product.

As soon as the said parameters fail to meet the predetermined standards, the ascending recovery well 15 is closed off with the gate 20, and recovery of oil therefrom is discontinued for the preassessed period of restoration of these parameters of the preset norm, during which period oil is recovered from the adjacent open recovery wells 15.

With the abovementioned period having lapsed, the said ascending recovery well 15 is reopened, and the liquid having in the meantime accumulated in this recovery well 15 flows at a high rate into the empty oil collector 21, causing a pressure drop at the face of the well 15.

The periodic closing of the ascending recovery wells 15 enables to vary the direction of infiltration flows of the fluid in the incoherent oil-bearing bed 3 and to increase the oil yield thereof; and when the heat-carrier is charged through the injection wells 5 as the pressurized fluid for forcing out oil, there is ensured the regulation of the thermal action upon the incoherent oil-bearing bed by maintaining the uniformity of the propagation of the heat-carrier throughout the volume of the bed; moreover, the conditions for the heat-carrier breaking through into the ascending recovery wells 15 are minimized.

This decreases the value of the consumption of the heat-carrier per weight unit of recovered oil and enhances the state of the atmosphere in the mine.

The periodic closing of the ascending recovery wells 15, followed by withdrawal of oil from the zone underlying the closing spot through the recovery gallery 8 to the ground surface also enables, and that without additional cost, to periodically create depressions acting upon the oil-bearing bed and to clear the near-face areas of the ascending recovery wells 15.

This enables to step up the productivity of the recovery wells 15.

The charging of the heat-carrier through the ascending recovery wells 15 into the oil-bearing bed 3 at the stage of heating the latter to a temperature whereat oil acquires sufficient fluidity in the oil-bearing bed 3 is preferably effected via tubes 22 (FIG. 11) accommodated within the casings 23 of the ascending recovery wells 15.

The about-tube space intermediate the casing 23 and the tubes 22 is sealed away at the mouth of the well with a plugging solution, e.g. one containing a liquid hydrocarbon and a pulverulent mineral weighing agent, such as finely ground silica with particle size short of 1 micron.

The said solution is to have a high boiling point, to prevent evaporation thereof in the outside-tube space, as it is heated by the heat-carrier.

The solution, which can be any suitable known per se one, is to be adequately stable, proof against disintegration within a preset time, sufficiently dense and viscous at elevated temperatures, of low heat conductivity and of fine sealing properties.

The sealing away of the mouths of the ascending recovery wells 15 at the stage of the charging of the heat-carrier at an elevated temperature into the oil-bearing formation enables to prevent the breakthrough of the heat-carrier into the recovery gallery 8 and to reduce the emanation of heat into the recovery gallery 8 on account of heat conductivity. This enhances the state of the mining atmosphere and reduces the ventilation costs.

What is claimed is:

1. A method of thermal-mine recovery of oil and fluent bitumens, which comprises

providing a system of mine working overlying an oilbearing formation;

drilling from said mine working and from the ground surface a plurality of injection wells adapted for charging a pressurized fluid therethrough into the oil-bearing formation; providing a slope and a man way in the area of the oil-bearing formation, where the provision of a recovery gallery is envisaged; providing the recovery gallery in this area of the oil-bearing formation;

drilling from said recovery gallery a system of horizontal and inclined oil recovery wells which are separate from the injection wells;

charging a heat carrier into the recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing formation, for uniform distribution thereof throughout the volume of the oil-bearing formation and for heating the latter to a temperature at which the oil acquires sufficient fluidity within the oil-bearing formation;

terminating the charging of the heat-carrier into said recovery wells upon the oil-bearing formation having attained the said temperature;

charging a pressurized fluid into the injection wells which are separate from the recovery wells and minimally associated with the highly permeable zones of the oil-bearing formation, to thereby directly supply the pressurized fluid through the injection wells into and to force oil from the oil-bearing formation into said horizontal and inclined recovery wells, toward said recovery gallery; and

withdrawing oil from said recovery gallery to the ground surface.

2. A method of claim 1, wherein said recovery gallery is provided in the lower part of the oil-bearing formation.

3. A method of claim 2, wherein, the heat-carrier is charged into the oil-bearing bed through the horizontal and inclined recovery wells to heat the oil-bearing bed until the latter is heated up to a temperature above which the viscosity of the oil at further heating is reduced but insignificantly.

4. A method of claim 3, wherein, prior to charging the fluid into the injection wells, the highly permeable zones of the oil-bearing bed communicating with these walls are filled with a plugging composition retaining oil-permeability of the porous body of the oil-bearing bed.

5. A method of claim 3, wherein, simultaneously with the charging of the heat-carrier into the oil-bearing bed through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing bed, oil is recovered through those of the horizontal and inclined recovery wells which have the minimum communication with the highly permeable zones of the oil-bearing bed.

6. A method of claim 3, wherein, at a later stage of the oil recovery from the oil-bearing bed the recovery gallery is periodically filled with a fluid of a density in excess of that of the oil bed.

7. A method of claim 1, wherein said recovery gallery is provided below the oil-bearing formation, to be separated therefrom by a low-permeability stable rock interbed.

8. A method of claim 7, wherein, the heat-carrier is charged into the oil-bearing bed through the horizontal and inclined recovery wells to heat the oil-bearing bed until the latter is heated up to a temperature above which the viscosity of the oil at further heating is reduced but insignificantly.

9. A method of claim 8, wherein prior to charging the fluid into the injection wells, the highly permeable zones of the oil-bearing bed communicating with these wells are filled with a plugging composition retaining oil-permeability of the porous body of the oil-bearing bed.

10. A method of claim 8, wherein, simultaneously with the charging of the heat-carrier into the oil-bearing bed through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil bearing bed, oil is recovered through those of the horizontal and inclined recovery wells which have the minimum communication with the highly permeable zones of the oil-bearing bed.

11. A method of claim 8, wherein, prior to the charging of the pressurized fluid into an incoherent oil-bearing bed an area in the lower part thereof is washed out with a liquid through the injection wells, whereupon said area is supplied with materials forming a stable oil-permeable structure and ascending recovery wells are drilled into this consolidated area of the oil-bearing bed.

12. A method of claim 1, wherein the heat-carrier is charged into the oil-bearing formation through the horizontal and inclined recovery wells to heat up the oil-bearing formation until the latter is heated to a temperature above which the viscosity of the oil decreases but insignificantly at subsequent heating.

13. A method of claim 12, wherein, prior to charging the fluid into the injection wells, the highly permeable zones of the oil-bearing bed communicating with these wells are filled with a plugging composition retaining oil-permeability of the porous body of the oil bearing bed.

14. A method of claim 13, wherein simultaneously with the charging of the heat-carrier into the oil-bearing bed through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing bed, oil is recovered through those of the horizontal and inclined recovery wells which have the minimum communication with the highly permeable zones of the oil-bearing bed.

15. A method of claim 13, wherein, at a later stage of the oil recovery from the oil-bearing bed the recovery gallery is periodically filled with a fluid of a density in excess of that of the oil.

16. A method of claim 13, wherein prior to the charging of the pressurized fluid into an incoherent oil-bearing bed an area in the lower part thereof is washed out with a liquid through the injection wells, whereupon said area is supplied with materials forming a stable oil-permeable structure and ascending recovery wells are drilled into this consolidated area of the oil-bearing bed.

17. A method of claim 1, wherein, prior to charging the pressurized fluid through the injection wells, the highly permeable zones of the oil-bearing formation comminicating with these injection wells are filled with a plugging composition retaining oil permeability of the porous body of the oil-bearing formation.

18. A method of claim 17, wherein simultaneously with the charging of the heat-carrier into the oil-bearing bed through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing bed, oil is recovered through those of the horizontal and inclined recovery wells which have the minimum communication with the highly permeable zones of the oil-bearing bed.

19. A method of claim 18, wherein, at a later stage of the oil recovery from the oil-bearing bed the recovery gallery is periodically filled with a fluid of a density in excess of that of the oil.

20. A method of claim 18, wherein prior to the charging of the pressurized fluid into an incoherent oil-bearing bed an area in the lower part thereof is washed out with a liquid through the injection wells, whereupon said area is supplied with materials forming a stable oil-permeable structure and ascending recovery wells are drilled into this consolidated area of the oil-bearing bed.

21. A method of claim 1, wherein, simultaneously with the charging of the heat-carrier into the oil-bearing formation through the horizontal and inclined recovery wells extending substantially across the dominating direction of the highly permeable zones of the oil-bearing formation, oil is being collected through those of the horizontal and inclined recovery wells, which have minimal communication with the highly permeable zones of the oil-bearing formation.

22. A method of claim 1, wherein at a later stage of the oil recovery from the oil-bearing formation the

recovery gallery is periodically filled with a fluid of a density in excess of that of the oil.

23. A method of claim 1, wherein, prior to charging the pressurized fluid into the incoherent oil-bearing formation, an area is washed away with a liquid in the lower part of this formation, into which area materials are supplied to form a stable oil-permeable structure, whereafter ascending recovery wells are drilled into this consolidated area of the oil-bearing formation.

24. A method of claim 23, wherein the faces of the injection wells are sealed, and the pressurized fluid is charged through the injection wells into the area of the oil-bearing formation, overlying the said consolidated area thereof, to force oil from the oil-bearing formation into the ascending recovery wells toward the recovery gallery.

25. A method of claim 23, wherein, simultaneously with the charging of the pressurized fluid into the injection wells, the ascending recovery wells are periodically closed, and following this closing, oil is recovered from the area underlying the closing points.

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(54) A Method for Continuously Producing Viscous Hydrocarbons by Gravity Drainage While Injecting Heated Fluids

(57) A thermal method for recovering normally immobile oil from a tar sand deposit, in which two wells are drilled into the deposit, one for injection of heated fluid and one for production of liquids. Thermal communication is established between the wells. The wells are operated such that heated mobilized oil and steam flow without substantially mixing. Oil drains continuously by gravity to the production well where it is recovered.

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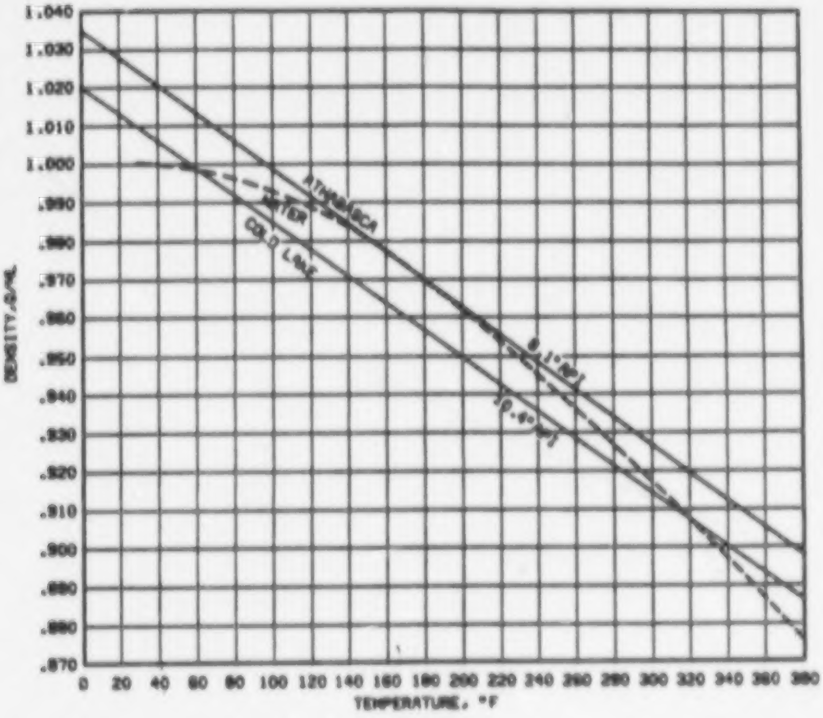
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40
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80
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120
140
160
180
200
220
240
260
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300
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360
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10.4°API

FIG. 1

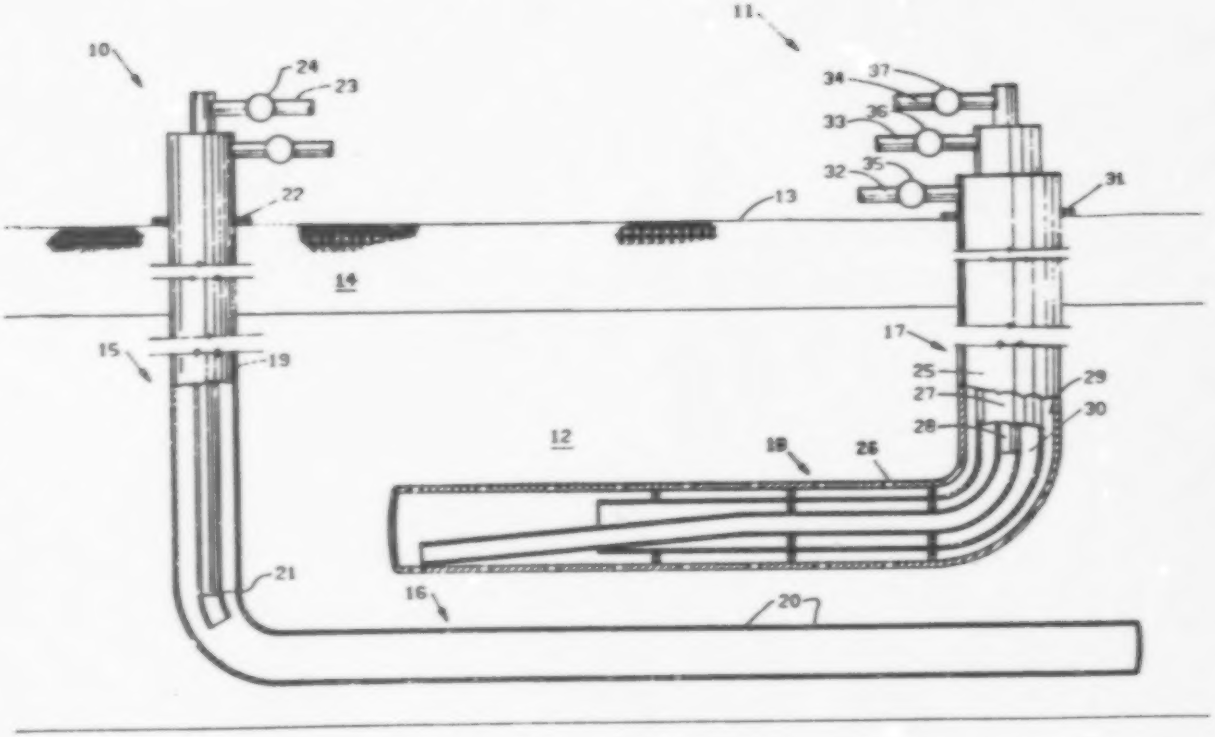

FIG. 2

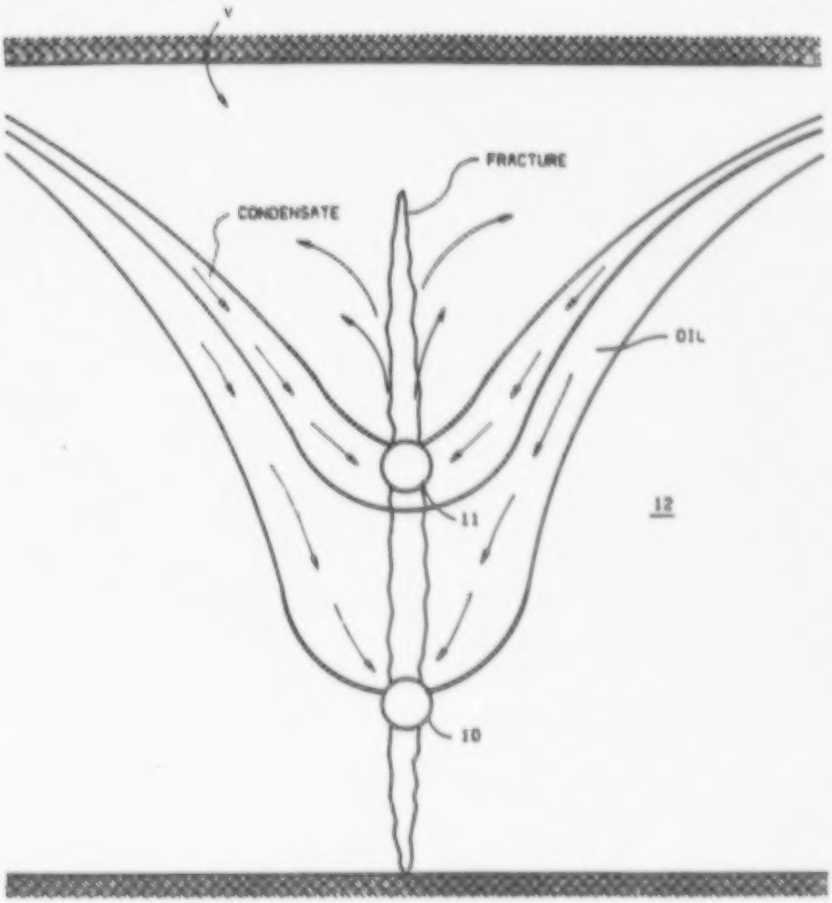
V
FRACTURE
CONDENSATE
OIL
11
12
10

FIG. 3

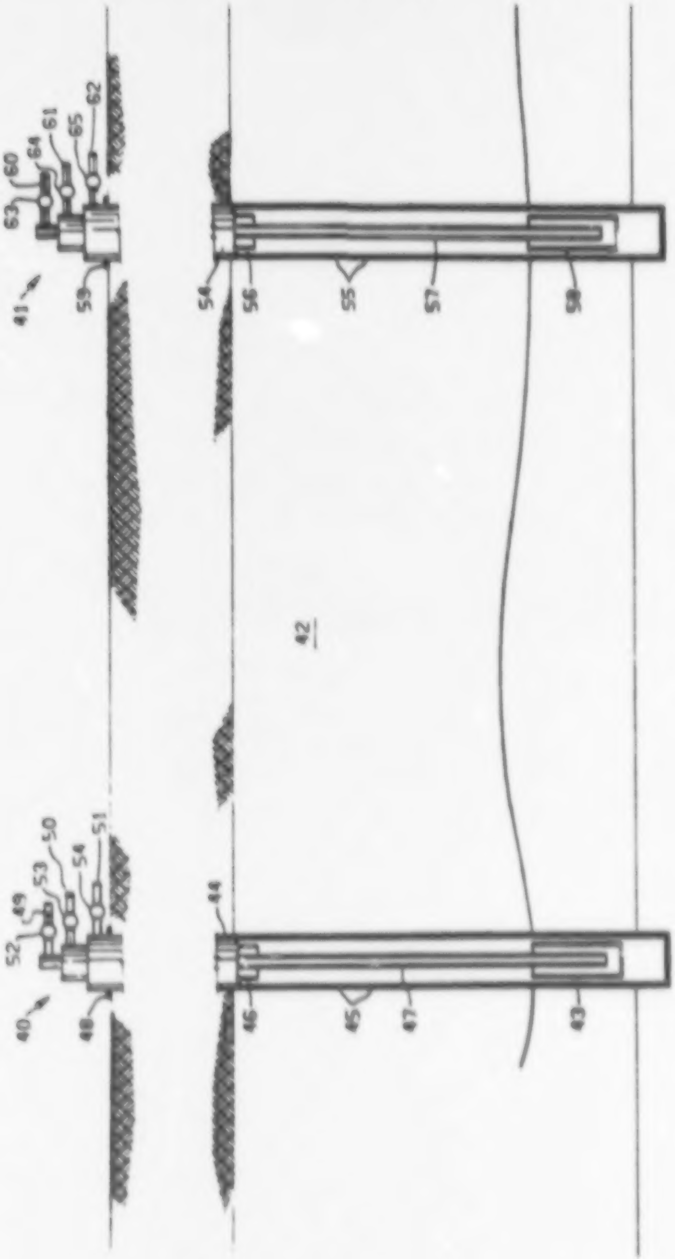

FIG. 4

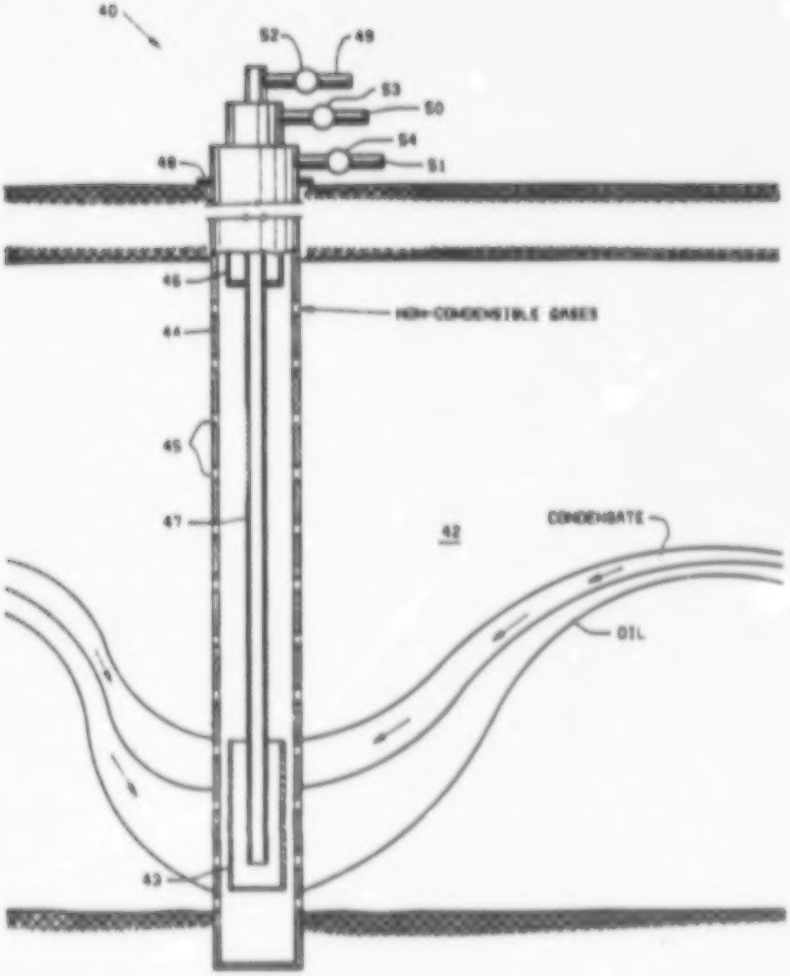
NON-CONDENSIBLE GASES
CONDENSATE
OIL

FIG. 5

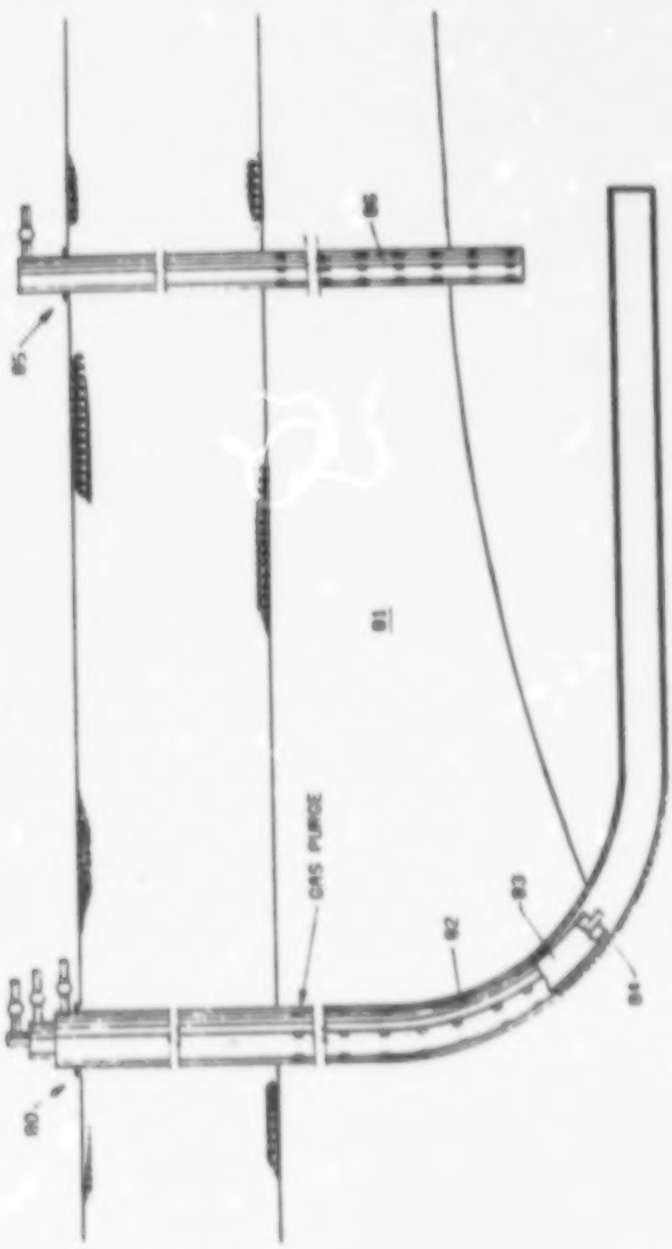
85
86
81
GAS PURGE
82
83
84
80

FIG. 6

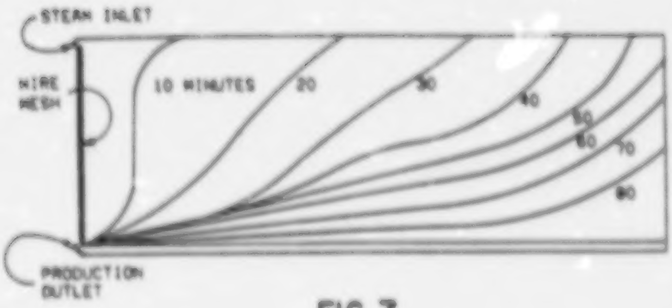
STEAM INLET
WIRE MESH
10 MINUTES
20
30
40
50
60
70
80
PRODUCTION OUTLET

FIG. 7

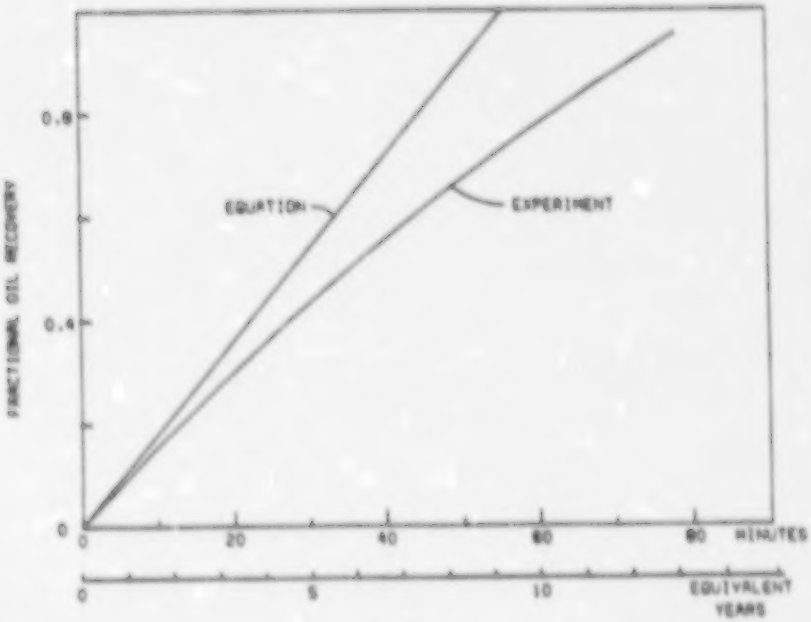
FRACTIONAL OIL RECOVERY
0.8
0.4
0
EQUATION
EXPERIMENT
0
20
40
60
80
MINUTES
0
5
10
EQUIVALENT YEARS

FIG. 8

SPECIFICATION

A Method for Continuously Producing Viscous Hydrocarbons by Gravity Drainage While Injecting Heated Fluids

This invention relates to a process for extracting hydrocarbons from the earth. More particularly, this invention relates to a method for recovering viscous hydrocarbons such as bitumen from a subterranean reservoir by continuously injecting a heated fluid to lower the viscosity of the viscous hydrocarbons concurrent with production of mobilized hydrocarbons.

In many areas of the world, there are large deposits of viscous petroleum, such as the Athabasca and Cold Lake regions in Alberta, Canada, the Jobo region in Venezuela and the Edna and Sisquoc regions in California. These deposits are often referred to as "tar sand" or "heavy oil" deposits due to the high viscosity of the hydrocarbons which they contain. These tar sands may extend for many miles and occur in varying thicknesses of up to more than 300 feet. Although tar sand deposits may lie at or near the earth's surface, generally they are located under a substantial overburden which may be as great as several thousand feet thick. Tar sands located at these depths constitute some of the world's largest presently known petroleum deposits. The tar sands contain a viscous hydrocarbon material, commonly referred to as bitumen, in an amount which ranges from about 5 to about 20 percent by weight. Bitumen is usually immobile at typical reservoir temperatures. For example, in the Cold Lake region of Alberta, at a typical reservoir temperatures of about 55°F, bitumen is immobile with a viscosity exceeding several thousand poises. However, at higher temperatures, such as temperatures exceeding 200°F, the bitumen generally becomes mobile with a viscosity of less than 345 centipoises.

Since most tar sand deposits are too deep to be mined economically, a serious need exists for an in situ recovery process wherein the bitumen is separated from the sand in the formation and produced through a well drilled into the deposit. Two basic technical requirements must be met by any in situ recovery process: (1) the viscosity of the bitumen must be sufficiently reduced so that the bitumen will flow to a production well; and (2) a sufficient driving force must be applied to the mobilized bitumen to induce production. Among the various methods for in situ recovery of bitumen from tar sands, processes which involve the injection of steam are generally regarded as most economical and efficient. Steam can be utilized to heat and fluidize the immobile bitumen and, in some cases, to drive the mobilized bitumen towards production means. Indeed, a majority of the processes currently employed utilize the injection of steam in one form or another.

Several steam injection processes have been suggested to heat the bitumen. One general method for recovering viscous hydrocarbons is by using "steam stimulation" techniques, the most common being the "huff and puff" process. In the process, steam is injected into a formation by means of a well and the well is shut-in to permit the steam to heat the bitumen, thereby reducing its viscosity. Subsequently, all formation fluids, including mobilized bitumen, water and steam, are produced from the well using accumulated reservoir pressure as the driving force for production. Initially, sufficient pressure may be available in the vicinity of the wellbore to lift fluids to the surface; as the pressure falls, artificial lifting methods are normally employed. Production is terminated when no longer economical and steam is injected again. This cycle may take place many times until oil production is no longer economical.

In the huff-and-puff method the highest pressures and temperatures exist in the vicinity of the well immediately following the injection phase. Normally this pressure and temperature will correspond to the properties of the steam which was employed. Before oil can be moved from the remote parts of the reservoir to the well, the pressure in the near well region must fall so it is lower than the distant reservoir pressure. During this initial depressuring phase, the near wellbore reservoir material cools down as water flashes into steam. The first production from the well thus tends to be steam and this tends to be followed by hot water. Eventually the pressure is low enough and oil can move to the wellbore. In the initial production phase, much of the heat which was put into the reservoir with the steam is simply removed again as steam and hot water. A major inefficiency of the huff-and-puff process is that this heat must be supplied during each cycle and as the available oil becomes more remote from the well, this cyclic wasted heat quantity increases.

The principal drawbacks of the "huff-and-puff" process, therefore, are : (1) production is not continuous, (2) the majority of the bitumen in the reservoir is never heated, thereby limiting recovery, and (3) the production cycle inherently removes most of the heating medium from the formation, and consequently much of the heating value of the injected steam is wasted.

A second general method for recovering viscous hydrocarbons is by using "thermal drive" processes. Typically, thermal drive processes employ an injection well and a production well, spaced apart from each other by some distance and extending into the heavy oil formation. In operation, a heated fluid (such as steam or hot water) is injected through the injection well. Typically entering the formation, the heated fluid convectively mixes with heavy oil and lowers the viscosity of the heavy oil, which is mobilized and driven by the heated fluid towards the production well. One advantage in using a thermal drive process is that higher recoveries may be obtained. For example, it has been the general experience in California that higher thermal efficiencies are achieved with steam stimulation, but that only relatively low recoveries are obtained overall. With steam floods, the recovery is higher, although more heat is used per barrel of produced oil.

Unfortunately, the general experience of industry has been that conventional thermal drive processes are not commercially effective in recovering bitumen from tar sands. One basic problem is that there is a restricted fluid mobility due to the high viscosity hydrocarbons cooling as they move through the formation; these cooled hydrocarbons build up away from the injection well to create impermeable barriers to flow. Another serious problem is that often the driving force of the flowing heated fluid is lost upon breakthrough at the production well. Fluid breakthrough causes a loss of driving pressure and a marked drop in oil production. In addition, much of the heating value of the heated fluid is lost upon breakthrough.

Various steam stimulation and thermal drive methods have been proposed in the prior art. For example, U.S. Patent No. 2,881,838 to R. A. Morse et al discloses a method for recovering viscous hydrocarbons wherein a single well is drilled through the producing formation; steam is then injected via the well into the upper portion of the formation to mobilize the viscous hydrocarbons which flow by gravity drainage to the bottom of the well; these mobilized hydrocarbons are then pumped to the surface. Steam is injected at rates calculated to continuously expand a heating zone in the formation as the mobilized heavy oil flows to the bottom of the well and is produced, but at the same time at rates which avoid substantial steam bypassing. A major disadvantage with Morse's process is that it contemplates only a radial process slowly growing from a vertical well. In such an operation, the heated surface during the initial stages is very small and only extremely low production rates are achieved.

In Morse, steam is introduced down the annulus of a well and liquids are produced up a central tubing. For this to be operable, it is necessary that at each point in the vertical well the steam be at a lower pressure than the pressure of the liquids in the inner tubing. If this is not the case, then heat will be transferred from the annulus through the tubing, condensing steam in the annulus, and boiling water in the tubing. This would be very wasteful. The Morse patent also suggests that a pump at the base of the well be able to overcome the hydrostatic head of liquid to the surface. In practice, it will also have to develop an additional pressure at the surface at least equal to the pressure of the injected steam, which may be uneconomical. The Morse patent also describes operation without a pump. If this were tried with the apparatus shown, then the pressure in the tubing would have to be less than the pressure in the annulus and excessive condensation of steam and flashing of water in the tubing would occur.

The Morse patent also does not recognize a problem which can arise from the evolution of non-condensable gas (natural gas) from the oil as it is heated. This non-condensable gas will mix with the steam and tend to accumulate near the interface. This will hinder the movement of the steam from the chamber to the interference where it is desired to condense it.

Yet another difficulty with the Morse process is that it recommends the use of a perforated and cemented casing for injection. A significant pressure drop would be required to cause injection of steam at practical rates from such a casing. This pressure difference would also be exerted at the bottom of the casing and would tend to prevent oil draining to the central production tubing.

U.S. Patent No. 3,960,214 to Striegler et al discloses another approach which involves drilling a horizontal injection well and positioning several vertical production wells above and along the length of the injection well. A heated fluid is circulated through the horizontal well to contact the formation, mobilizing the bitumen which is then recovered through the vertical production wells. A problem sought to be addressed by this patent is that of providing a permeable, competent communication path between injection and production wells, thereby avoid the problems of cooled bitumen banking up to create impermeable barriers to flow. However, the mechanism of recovery is not clear and clearly does not depend on gravity drainage of heated oil.

Another example of a thermal drive method for continuously producing viscous mobilized viscous hydrocarbons is Canadian Patent No. 1,028,943 to J. C. Allen. This patent proposes that prior to injecting steam into a formation, a non-condensable and non-oxidizing gas be injected to establish an initial gas saturation. Following this, a mixture of steam and non-condensable gas are injected. By utilizing this method, it is said that pressure communication between an injection well and a production well can be maintained and also premature pressure decline is avoided. Flow of oil from one well to the other is caused by lateral pressure differences; a gravity drainage process is clearly not involved.

Major problems still exist with each of these processes, in particular, and with thermal drive processes in general. One problem stems from the fact that the injected steam condenses and mixes with the mobilized bitumen as these fluids move through the formation. Any significant mixing of the mobilized heavy oil and condensed water results in a greatly reduced oil relative permeability. A second problem is that low steam injection pressures are often required to avoid the formation of fractures within a reservoir. However, at such pressures, it may not be possible to inject steam having enough heating value to economically heat the formation and mobilize the bitumen. A third problem is that as steam injection continues and the reservoir is heated, non-condensable gases contained in the formation will fractionate and accumulate in the reservoir. If this occurs to a significant extent, oil production can decline and stop due to a pressure buildup which counteracts oil flow.

Therefore, while the above methods are of interest, the technology has not generally been economically attractive for commercial development of tar sands. Substantial problems exist with each process of the prior art. Therefore, there is a continuing need for an improved thermal process for the effective recovery of viscous hydrocarbons from subterranean formations such as tar sand deposits.

In accordance with the present invention, an improved thermal recovery process is provided to alleviate the above-mentioned disadvantages; the process continuously recovers viscous hydrocarbons by gravity drainage from a subterranean formation with heated fluid injection.

An injection well for injecting a heated fluid, preferably steam, and a production well for producing oil and condensate are drilled into the formation. In the preferred embodiment, the wells are located along the fracture trend of the formation. The wells are completed such that separate oil and water flowpaths in at least the near-wellbore region of the production well are ensured with appropriately throttled injection and production rates. Initially, the formation is preferably fractured by injecting the heated fluid via the injection well at higher then fracture pressure. Alternatively, a suitable fracturing fluid may be used to create a fracture.

Steam may be injected via the injection well to heat the formation. Injectivity is high and, in the preferred embodiment, a highly permeable flowpath is immediately established due to the fracture between the wells. As the steam condenses and gives up its heat to the formation, the viscous hydrocarbons are mobilized and drain by gravity toward the production well. Mobilized viscous hydrocarbons are recovered continuously through the production well at rates which, due to the construction of the wells, result in substantially separate oil and condensate flowpaths without excessive steam bypass. Oil relative permeability is higher than with prior methods wherein mixed flow occurs to a substantial extent.

In carrying out this invention, the conditions are chosen so that a very large steam saturated volume known as a steam chamber is formed in the formation adjacent to the injection well. The injection well must be connected to this chamber and steam is injected continuously so as to maintain pressure. At the boundary of the chamber, steam condenses and heat is transferred by conduction into the cooler surrounding regions. The temperature of the oil adjacent to the chamber is increased and it drains downwards, along with the hot steam condensate. The oil is removed continuously at a point below the chamber. As the oil drains downwards, it flows substantially separate from the steam and preferably separate from the condensate. This allows the relative permeability for the movement of oil to be maintained at a high value.

Various well configurations may be utilized to accomplish the method of the present invention. The following features are common to all configurations: (a) a production well is utilized which is "extended" through the tar sand formation, either as a horizontal well or by creating a fracture (or a combination of the two); (b) "thermal communication" between the injection and production wells is established before commencing production of oil; and (c) the injection and production wells are completed such that substantially separate oil/steam (and preferably oil/condensate) flowpaths can be maintained. The expression "separate flowpaths" is taken to mean flow without substantial mixing of the fluids, although some mixing will occur at fluid interfaces. The expression "thermal communication" is intended to mean that a relatively high permeability path at temperatures greater then normal reservoir temperatures is established from the injection well to the production well so that liquid heated by injected steam can drain continuously to the production well. In some cases condensate from injected steam may also flow to the production well. A predetermined saturation of mobilized heavy oil buildup is promoted and maintained adjacent to the lower portion of the production well, thereby providing increased oil relative permeability. The production well may be "extended" by drilling a horizontal well through the formation (either a deviated well or by drilling from a shaft or tunnel), or by forming a vertical fracture out into the formation from the production well. Also, any produced non-condensable gas is preferably purged from the steam chamber to the production well, i.e. some steam is allowed to move from the production well to keep the non-condensable gases flushed from the steam chamber.

In one embodiment, two nearly horizontal wells, one located directly above the other, are drilled into a formation and completed along a fracture trend. The upper well is used to inject steam and remove water and condensate, while the lower well is used to produce mobilized viscous oil. Production of oil is regulated so that separate oil and water flowpaths are maintained and excessive steam bypass is avoided. Preferably, any non-condensable gas which fractionates during steam injection is purged by means of a well connection to the upper part of the steam chamber. Such a connection may be a completely separate well or a connection to the annulus of that portion of the production well which is vertical. Production is regulated to prevent excessive steam bypass.

In another embodiment, two vertical wells are drilled through the formation and spaced from each other along the fracture trend of the formation. Each well is completed with weir means at its lower end. The function of the weir means is to promote separate oil/steam/water flowpaths in the formation by ensuring a fluid buildup in the wellbore. Steam is initially injected into the formation by means of one well at a pressure calculated to fracture the formation; alternatively a conventional fracturing fluid may be used for this purpose. With continued steam injection, immobile viscous oil is heated by conduction and begins to flow as its viscosity lessens. The mobilized viscous oil drains by gravity to both wells under pressure, where it is produced at rates regulated so to ensure fluid buildup in the wellbores and to avoid excessive steam bypass.

In yet another embodiment, a horizontal well is extended into and along the lower portion of the formation in the direction of the prevailing fracture trend. A vertical well is located a short distance above the horizontal well. Again, both wells are completed in such a manner as to promote separate oil-water flowpaths. Steam is injected by means of the vertical well, and heavy oil is produced by means of the horizontal well. Again, any non-condensable gases which fractionate are purged through the horizontal well.

For each well configuration briefly described above, the method of the present invention finds particular application where the viscous hydrocarbons have a density when initially mobilized (i.e., when heated to a temperature sufficient to flow in the formation) which is greater than the density of the hot aqueous condensate which may form such as hot water which condenses from the injected steam. It has been found that this is typically the case for many viscous hydrocarbon deposits.

The present process substantially reduces problems found with conventional thermal processes and provides a much more uniform sweep of the reservoir. Instead of the flow of steam being confined to certain favorable passages within the reservoir, a process is provided which allows the steam to pervade the entire reservoir region. By utilizing gravity to move the oil downwards, along with a steam chamber which expands continuously to replace the drained fluids, the reservoir volume can be contacted in a methodical manner. This yields a high recovery, the process can be operated at low pressure. Relatively high production rates are achieved by using an extended well system—either a horizontal production well or a fractured well system, or a combination. The problem of reduced oil relative permeability associated with injecting hot fluids into viscous hydrocarbon-containing formations is mitigated by promoting separate oil/water flowpaths. Further, steam injection rates and product recovery are facilitated by preferably injecting steam at pressures which are initially above the formation fracture pressure. By permitting fracturing to occur, better communication is immediately provided for flowing mobilized viscous hydrocarbons. In practicing the method, it is especially preferred to vent any non-condensable gases which may fractionate during steam injection. This promotes the efficient transport of the steam to the steam chamber/heavy oil interface.

The invention is described with reference to the drawings in which:

Figure 1 is a plot of density versus temperature for Cold Lake and Athabasca heavy oil and water.

Figure 2 is schematic vertical cross-section of a well configuration suitable for practising the invention.

Figure 3 is a schematic end view in section of the well configuration of Figure 2.

Figure 4 is a schematic vertical cross-section of a second well configuration for practising the invention.

Figure 5 is a schematic end view in section of the well configuration of Figure 4.

Figure 6 is a schematic vertical cross section of a third well configuration for practising the method of this invention.

Figure 7 is a schematic side view of a small scale model of the well configuration of Figures 2 and 3.

Figure 8 is a plot of fractional oil recovery versus time.

The method of the present invention provides for continuous steam injection and heavy oil production in an efficient and economical manner. All of the well configurations disclosed herein have several basic operating features in common. First, a relatively large steam chamber in the tar sand formation is promoted by utilizing an "extended" production well. The production well is "extended" by forming a horizontal length through the formation, or by fracturing the formation between the production and injection well, or by using a combination of these approaches. The term "steam chamber" means the volume of the reservoir which is saturated with injected steam and from which mobilized oil has drained. Fracturing facilitates the injection of steam and, moreover, immediately establishes a highly permeable flowpath for the flowing heavy oil. Thermal communication between the injection and production wells is quickly established thereby. While the fracture can be formed initially by using high steam pressure it is desirable to operate at low steam pressures once the process has been established. This increases thermal efficiency. Second, each well configuration is designed to promote separate flowpaths for steam and liquids, and preferably substantially separate steam, water and oil flowpaths, with carefully regulated production rates. As will be described below, this significantly enhances oil relative permeability, increasing oil recovery efficiency. Third, the production rates of water and heavy oil are closely controlled to provide optimum oil production without excessive steam bypass. In addition, it is especially preferred to vent any non-condensable gases which may accumulate in the reservoir during injection of steam and recovery of product.

Finally, the method is especially suited for certain reservoir conditions; namely, the heavy oil when initially mobilized preferably should have a density which is greater than the density of hot aqueous condensate. It has been determined that several very important heavy oil deposits satisfy this requirement. This may best be illustrated by reference to Figure 1. For example, if steam were injected at 380°F it will have a density of 0.007 g/ml. The oil when initially mobilized will be at a temperature of 380° or somewhat less. At these temperatures, Cold Lake crude oil will have a density of 0.886 g/ml or greater and Athabasca crude oil will have a density of 0.899 g/ml or more. Both values are greater than the density of the hot aqueous condensate, which would be about 0.875 g/ml. The condensate will thus tend to float on the oil.

Generally, in practising the invention, the surface of the steam chamber must be very large since the gravity drainage process is very slow. By heating a large chamber area, the total flow of oil can be maintained at a practical value. "Chamber area" means the area of the steam chamber's outer surface boundary. For example, in the conduct of the invention, steam chambers as much as 1000 ft. long and 100 ft. high and 50 ft. in width (or larger) may be formed in a relatively short period of time, e.g. 10 to 100 days. Such a chamber can have a surface area measured in hundreds of thousands of square feet and, even with a viscous oil sands material such as that at Cold Lake, can produce total drainage rates measured in hundreds of barrels per day. In practising this invention, the injection and production wells are designed such that a steam chamber having a surface area greater than 30,000 square feet can be formed within about 365 days and preferably within about 180 days or less; the formation of a chamber having a surface area of 50,000 square feet or more within about 365 days (preferably within about 180 days or less) is especially preferred.

The use of a simple vertical well with heat conducted radially would produce an initial steam chamber having an area of no more than a few hundred square feet and growing only very slowly, and would not be suitable for the practice of this invention. For the process described herein to be practical, it is necessary to develop steam chambers having very large surface areas relatively quickly. In the preferred embodiment of this invention, this is accomplished by developing a vertical fracture between the injection well and the production well and injecting steam into this fracture. The initial resulting steam chamber is thus very narrow in width but has considerable vertical and horizontal dimensions. This fractured chamber may be formed by initially employing steam pressure above the fracture pressure or by hydraulically fracturing the reservoir and propping it using appropriate proppants. Once the process has proceeded and substantial steam saturation has been achieved surrounding the original fracture, the fracture itself becomes less important since thermal communication in the form of a steam saturated volume has been established. At this stage, if the fracture was initially formed by using very high pressure steam, the pressure can be reduced and the process continued using steam at subfracturing pressure.

It is important to note that the pressure needed to form the fracture initially need not necessarily be maintained throughout the life of the well. Thus, for example, it is possible to initially operate the injection well at pressures greater than that needed to fracture the ground, but once a narrow steam chamber and mobile zone has been formed to allow the pressure to fall and to operate at sub-fracturing pressures. Operation at very high pressures, and consequently high temperatures, in many cases would be wasteful of heat; less steam would be used to heat the reservoir to the lower temperatures corresponding to lower pressures.

Before discussing the method in detail with reference to the various well configurations depicted by Figures 2—6, the importance of promoting separate oil/water flowpaths should be emphasized. In prior art processes, much of the steam injected condenses and mixes with the mobilized oil as these fluids flow towards the production means. Because the oil and water mix, the oil relative permeability is significantly reduced. Permeability is the measure of the ease with which a fluid flows through the pore spaces of a formation. With high permeability, fluids will flow easily through the formation, while with low permeability, fluids will not move very readily. Permeability is an important economic indicator because it is one of the primary factors governing the rate at which oil and gas will move to the wellbore. The term relative permeability is utilized when a formation is saturated with more than one fluid, and is used to express the permeability of the formation to each fluid individually. Anything that would tend to decrease the relative permeability of a formation to the flow of oil is to be avoided. The magnitude of the reduction in oil relative permeability as between mixed oil/water flow and separate flow is illustrated by the following Table I:

Table I

Relative Permeabilities Mixed Versus Separate Oil/Water Flow

	Oil Relative Permeability	
Water/Oil Ratio	*Separate*	*Mixed*
0	1.0	1.0
1	0.36	0.10
2	0.20	0.04
3	0.23	0.02

Table I indicates that water flowing with the mobilized heavy oil causes some reduction in oil relative permeability during flow in substantially separate flow paths, but that with mixed flow the reduction is vastly greater. This clearly illustrates the importance of promoting separate paths for the flow of the steam into the expanding steam chamber, the condensate and the mobilized heavy oil to the production means.

It should be noted that the use of the expression "substantially separate" is not meant to imply that mixing will not occur; on the contrary, as the water/oil interface there will certainly be mixing. However, by practising the method disclosed herein, the majority of mobilized oil will flow seperately from the steam and preferably from the aqueous steam condensate.

Referring now to Figure 2, one embodiment of a well configuration utilized in practising the present invention is schematically depicted. A first wellbore 10 and a second wellbore 11 are drilled to penetrate tar sand formation 12 disposed below the earth's surface 13 and beneath an overburden 14. The wells 10 and 11 are located so that they are in line with the fracture trend of the formation 12; these wells also "point" towards each other which has been discovered to facilitate purging of fractionated noncondensible gases, although the invention could be practiced with these wells pointing in the same horizontal direction. The wellbore 10 has a substantially vertical section 15 and a substantially horizontal section 16 extending through the tar sand formation 12. Likewise, the wellbore 11 has a substantially vertical section 17 and substantially horizontal section 18, approximately paralleling the first well. Each well is fitted with a continuous casing or liner having perforations or preferably slots over a substantial distance along the horizontal section. In practising the present invention the wellbore 11 when completed is utilized as a steam injection well while the well 10 is utilized to produce the heavy oil.

Production well 10 includes casing 19 having a number of perforations 20 or, preferably, slots located over a substantial distance of horizontal portion 16. It is preferred to have the slotted portion of the horizontal production well extend up the vertical section nearly to a point somewhat above the horizontal section. This will permit venting of the steam from the upper slots in order to remove non-condensable gas from the steam chamber. A production tubing string 21 is disposed inside casing 19. The embodiment of Figure 2 shows the production tubing 21 extending approximately to the base of the steam injection well. This prevents the liquid level being drawn below that point, i.e. this ensures that liquids fill the horizontal portion of the well. Centralizers are installed at various intervals in the annular space between tubing string 21 and casing 19; these centralizers are not continuous and do not block fluid flow in the annular space. Tubing string 21 passes through a wellhead 22 and communicates with a conventional production conduit 23 having a conventional flow control valve 24.

Injection well 11 includes casing 25 having perforations 26 along the horizontal section 18 which are in communication with the tar sand deposit 12. It may also be desirable to have the perforations extend up the vertical section nearly to the top of the injection well. This will allow this section to be used for the injection of some of the steam and allow easier entrance of the aqueous condensate to the horizontal section. As mentioned, having the two horizontal wells in opposing directions allows non-condensable gases to be swept to the production well more easily. Dual concentric tubing strings 27 and 28 are disposed inside the casing 25. The inner tubing string 28 is disposed within the surrounding larger diameter outer tubing 27. Conduit 25, 27 and 28 cooperate to define annular spaces 29 and 30. As with production well 10, centralizers are installed at various intervals in annular spaces 29 and 30 to maintain the annular relationship of the tubing strings and casing. The concentric conduits 25, 27 and 28 pass through a wellhead 31 and communicate with the usual production conduits 32—34 having the usual flow control valve 35—37.

The horizontal sections of both wells 10 and 11 can be inclined slightly downward. The techniques for drilling horizontally deviated wellbores are well known and, therefore, will not be discussed in detail herein. Likewise, the mechanics of completing a well are generally well known in the art; further details may be found in U.S. Patent No. 4,116,275 to Butler, et al.

After completing production well 10 and injection well 11, the method of the present invention is accomplished as follows. With valve 24 of production well 10 closed, steam is injected via conduit 32 at pressures which exceed the fracture pressure of formation 12. For example, where the fracture pressure of formation 12 is 1200 psig, steam is introduced at 1300 psig at a saturation temperature of 580°F. A vertical fracture is formed in tar sand deposit 12 extending above and below each well. The light steam tends to rise in the fracture and into the formation where it condenses and gives up its heat to the deposit 12. As the steam condenses and drains downward to the injection well 11, heat is transferred by conduction to the deposit 12 and the heavy oil within it is heated. The heating of the heavy oil reduces its viscosity and allows it to drain by gravity downward towards the production well 10; the oil flows below the water flow to the upper well 11. After the drainage process has begun and a steam chamber has formed, the steam injection rate is reduced and the steam chamber pressure is allowed to fall to the desired operating value. Typically, this will be in the range 100—500 psig depending upon the characteristics of the reservoir. With the equipment shown, sufficient pressure must be maintained to lift the produced fluid to the surface. This required pressure will be less than might be expected, however, because much of the volume of the wellbore will be full of steam which is formed by the flashing of water in the produced fluids. For example, a pressure difference of the order of 200 psi is sufficient to lift the fluid over 1000 feet. In general, higher pressures will give faster production rates but will require more heat per barrel of produced oil.

A better perspective of the process may be gained by reference to Figure 3, which illustrates operation of the process after a portion of the heavy oil in place has been recovered. As can be seen, the vertical fracture travels along the axis of both wells 10 and 11. A certain volume V of deposit 12 has been heated and the heavy oil therein has drained to production well 11. Aqueous condensate and oil drain by substantially separate flowpaths towards the wells due to the particular configuration of the wells and with appropriately throttled production rates. Condensate is recovered via well 11 while oil is recovered via well 10. The production rate of oil is regulated so that injected steam does not excessively bypass into well 10 and so that mixing of oil and water is minimized at least in the near-wellbore region of the formation. As a practical matter, this means that the flow of oil into any given portion of well 10 will be low; however, due to the long horizontal portion of well 10, overall production rates will be relatively good. Moreover, the efficiency of oil recovery will be very good, since substantially separate oil and condensate flowpaths are maintained during production. Expressed differently, this invention results in a relatively high oil saturation in the reservoir adjacent to the horizontal portion of the production well, and a relatively low water and steam saturation in the same region. This is different from conventional thermal drive processes wherein the primary heat transfer mechanism is forced convection, e.g. requiring that steam mix with oil. Thus, oil saturations may be maintained as high as S_o (naturally occurring oil saturation) or higher and water saturations may be as low as S_w (naturally occurring water saturation) or lower.

The heating value of the steam is fully utilized. Moreover, waste heat is more conveniently recovered from the hot condensate.

As mentioned, the present invention finds particular application where the heavy oil or bitumen has a greater specific gravity than that of hot water; this relationship is unlike that with many other crude oils. Thus, movement of oil and condensate through the formation towards the lower production well is promoted without substantially mixing with steam, and preferably with each other. Hence, an excessive reduction in oil relative permeability is avoided. Drainage of the mobilized heavy oil into production well 10 is facilitated initially by the presence of the fracture which passes through the wells. In the production well 10, oil is collected in the production tubing string 21 at the lowest point and flows to the surface driven by the prevailing reservoir pressure which is close to the steam pressure.

It is desirable to throttle the flow of oil by means of valve 24 at the surface so as to prevent water from entering into the production well 10. This valve may be controlled as to maintain the oil production temperature measured at the bottom of the well at a fixed level below the temperature of the steam. As steam injection continues, a certain amount of non-condensable gas will build up in the formation and which is preferably vented via the upper portion of well 10.

At the same time that oil is produced from well 10, aqueous condensate is flowing back to the injection well 11. Removal of condensate from well 11 is controlled by throttling the flow using valve 37 so as to maintain a small pool of water at the bottom of the injection well which prevents direct steam bypassing. Alternatively, a simple steam trap could be installed at the bottom of tubing string 28. This would prevent condensate from flowing upwards but would close if steam began to bypass. Also, a gas or other thermal insulating means may be introduced into annular space 29 to reduce heat transfer between the injected steam and the produced condensate.

Equation 1 may be derived for estimating the productivity (Q) of a well system of this type:

$$Q=0.0264\,L\sqrt{\frac{\phi S_o \alpha K H}{m \nu_s}} \qquad (1)$$

L Length of well in feet
ϕ Fractional porosity of reservoir
S_o Fractional Oil Saturation
α Thermal diffusivity of reservoir ft^2/day
K Permeability within oil saturated region md
H Height from top of reservoir to interface above the drainage well in feet
m A dimensionless number determined by the rate of change of viscosity of the crude with temperature. Normally it is between 3 and 4.
ν_s Kinematic viscosity of the crude at steam temperature in centistrokes.
Q Oil drainage rate in B/D.

Using Equation 1, it is estimated that productivity would be about 0.2 to 1.0 barrel per day of heavy oil per foot of reservoir. Thus, a double horizontal well system as depicted in Figure 2 having a length of 1200 feet extending through the tar sand deposit 12 should produce 240 to 1200 barrels per day.

In operating the well configuration of Figure 2, steam is continuously injected and heavy oil continuously produced such that substantially separate oil and water flowpaths exist in the reservoir, at least in the wellbore region near the production well. Moreover, because most of the waste heat from the wells arrives at a constant temperature in the hot water stream at conduit 34, it is possible to recover much of this relatively high grade heat.

Figure 4 depicts another embodiment for performing the method of the present invention. Two wells 40 and 41 are drilled through tar sand formation 42 and spaced along the prevailing fracture trend. Both wells are completed in the same manner. Thus well 40 includes a continuous casing 44 having perforations or slots 45 (preferably slots) along the length of the casing 44 which traverses the tar sand deposit 42. An intermediate tubing string 46 is extended through casing 44 and ends near the top of formation 42. A production tubing string 47 is extended through both the intermediate tubing 46 and casing 44. The tubing string 47 extends to near the bottom of the formation 42 and is fitted with a cylindrical section of tubing 43 which is closed at the bottom, but open at the top. The tubing section 43 acts as a weir to ensure that a level of liquids builds up in the wellbore above the bottom of the production tube 47. This in turn has been found to promote separate oil and water flowpaths in at least the near-wellbore region. Again, centralizers may be utilized to maintain the various conduits in a space relationship; these centralizers should not significantly impede fluid flow. The concentric tubing strings and the casing pass through a wellhead 48 having the usual production conduits 49—51 and conventional flow control valves 52—54. The well 41 is completed in a similar manner and includes casing 54 having slots (preferably) or perforations 55, an intermediate tubing string 56, and inner tubing string 57 fitted with weir means 58. The concentric tubing strings and casing pass through a wellhead 59 fitted with conventional valves 63—65 and production conduits 60—62.

In practising the method utilizing the well configuration depicted in Figure 4, steam is injected via conduit 62 into the tar sand deposit 42 through the annulus formed by casing 54 and tubing 56. The injection pressure is preferably above the fracture pressure of the formation initially so as to create a vertical fracture running generally in the direction of the well 40. The length of the fracture may be as long as the distance between wells 40 and 41, but usually no longer than from 200 to 1000 feet. It is also possible to form the fracture by hydraulic fracturing and to prop the fracture open using conventional techniques. Initially, valves 63, 64 and 52—54 are closed. Once the fracture has formed, valve 52 may be opened to induce flow of condensate and oil along the fracture towards well 40. Steam is introduced continuously, flowing with relative ease along the fracture and with more difficulty at right angles to the fracture into the formation itself. Alternatively, steam can be injected into both wells simultaneously until thermal communication is established between wells. As the steam condenses and gives up its heat by conduction to the formation, the previously immobile bitumen begins to flow. The viscosity of the oil may change from 100,000 centipoise to less than 15 centipoise as it is heated. The density of the oil may change from 1.0 to 0.98, but is greater than the density of the hot, pressurized condensate which will have a density of about 0.88. Thus, the mobilized heavy oil begins to drain by gravity towards the well 40 along the fracture. Water formed by the condensation of the steam flows by gravity back towards the well 40 in a flowpath which is substantially different than the flow of the mobilized oil. Because the density of the mobilized oil is greater than the density of any condensate which forms, the condensate in essence "floats" on top of the oil.

Initially, the production rate of oil and condensate is maintained at a very low level by means of valve 52. This permits the steam to gradually heat the formation 42. As more oil is mobilized and flows downward in the formation and towards well 40 by gravity, the rate of production is gradually increased until an optimum rate is achieved. This rate will be that which gives substantially separate flowpaths, at least in the nearwell region of well 40, and does not permit any significant steam bypass.

Figure 5 illustrates the process from another perspective after some time has passed. The production well 40 is shown in section and the shape of the expanded steamed zone may be seen. Figure 5 also illustrates the operation of the weir means. In order to prevent mixing of the flowing oil and water layers as they near the bottom of the well 40, an internal weir 43 is connected to the bottom of the production tube 47. The weir ensures that a level of liquids builds up in the wellbore above the bottom of the production tubing 47. The rate that water and oil are produced from the well is closely controlled by means of valve 52 so that the liquid level in the annulus between weir 43 and tubing string 47 is maintained below the top of the weir 55. By operating in the described manner, water drains back to the well through an essentially separate path from that used by the oil, especially in the near-wellbore region. Thus, a high oil relative permeability is promoted which enhances production. Steam is continuously injected and heavy oil is continuously produced at rates such that substantial steam bypass does not occur.

It is especially preferred that any non-condensable gases which collect in the steam zone be purged via well 40. Non-condensable gases such as methane, ethane or propane which are dissolved in the oil tend to be stripped by the steam and accumulate in the upper region of the deposit 42 which is saturated with steam. If this occurs to an excessive extent, the recovery process slows down and can become inoperable. In operation, with reference to Figure 4, there is a net flow of steam and gas into the well 61. The bottom hole pressure of the well 40 is controlled at a level which is somewhat below the injection pressure of well 41. Non-condensable gases are purged at a rate which is calculated to maintain a relatively high steam chamber temperature and relatively high production rates, but at the same time so that excessive steam by-passing does not take place.

Another embodiment is depicted by Figure 6. In this well configuration, a horizontal well 80 is extended near the bottom of tar sand deposit 81. Well 80 is completed with a perforated or slotted casing 82 and concentric tubing strings 83 and 84, which terminate inside casing 82 at a level near the bottom of injection well 85, i.e. such that a relative long portion of slotted casing 82 extends into the formation free of the inner tubing strings. This manner of completion together with the appropriate production rate will ensure that the main horizontal part of well 80 remains full of liquid. This is important as with the other embodiments to promote substantially separate steam/liquid flowpaths, and preferably steam/water/oil flowpaths (in other words, a relatively high oil saturation adjacent to the horizontal portion), and hence higher oil relative permeability. The horizontal well is preferably drilled so that it extends along the fracture trend of the formation.

A vertical well 85 is drilled so that it extends near to the top of the horizontal portion of well 80. The bottom of well 85 will preferably extend to within about 5 to 10 feet from the top of well 80, but depending on the nature of the formation may be as far as 100 feet. Smaller distances will be used if it is desired to achieve thermal communication without fracture or if the direction of fractures is hard to predict. Well 85 is completed with a slotted liner 86 for steam injection.

In operation, steam is injected into the formation via well 85 above the fracture pressure of formation 81. A fracture forms approximately along the direction of the axis of well 80 to immediately provide, as before, a high permeability flowpath for steam, condensate and mobilized heavy oil. Mobilized heavy oil drain towards the nearly horizontal portion of well 80. Tubing strings 83 and 84 terminate at a distance which is calculated to maintain the main horizontal portion of well 80 full of liquid with throttled production. The described configuration promotes separate oil and water flowpaths thereby maintaining high oil relative permeability. In addition, any non-condensable gases which may accumulate in the deposit 81 are purged near the top of the reservoir via the outer annulus of well 80 via the slots in casing 82. These slots extend up the casing 82 to near the top of the reservoir.

Operation with a horizontal well, but without an initial fracture, may be desirable in cases where it is desired not to employ very high pressures. One example of where this may be important is in the drainage of oil from oil sands that are not very deeply buried and where fracturing may be uncontrollable. The technique can also be used where it is desired to drill the horizontal production well in a direction other than along a fracture trend; for example, it may be desired to drill it perpendicularly from the shore of a small lake which contains an oil sand reservoir beneath it. In such cases it is particularly desirable to have the injection well closer than usual to the horizontal well so that initial thermal communication may be established fairly rapidly by thermal conduction.

It may be noted that the well 80 is depicted with a triple tubing completion. In many cases, a dual tubing completion would suffice. Also, well 85 may be completed with a production tubing for production of liquids and may be a triple tubing completion so that insulating gas can be introduced into the annulus between the inner two tubing strings.

The term heated fluid, as used herein, is understood to mean a fluid having a temperature considerably higher, e.g. 150°F to 1000°F, than the temperature of formation into which it is injected. It could be a heated gas or liquid such as steam or hot water and it could contain surfactants, solvents, oxygen, air, inert inorganic gases, and hydrocarbons gases. However, because of its high heat content per pound, steam is ideal for raising the temperature of a reservoir and is especially preferred for practicing this invention. Saturated steam at 350°F contains 1192 btu per pound compared with water at 350°F which has only 322 btu per pound or only about one-fourth as much as steam. The big difference in heat content between the liquid and the steam phases is the latent heat or heat of evaporation. Thus, the amount of heat that is released when steam condenses is very large. Because of this latent heat, oil reservoirs can be heated much more effectively by steam than by either hot liquids or non-condensable gases.

In all embodiments described above, several factors affect the volume of steam injected. Among these are the thickness of the hydrocarbon-containing formation, the viscosity of the oil, the porosity of the formation, amount of formation face exposed and the saturation level of the hydrocarbon, water in the formation and the fracture pressure. Generally, the total steam volume injected will vary between about 1 and about 5 barrels per barrel of oil produced. Moreover, the steam may be mixed with other fluids, e.g. gases or liquids such as water, to increase its heating efficiency.

Steam is injected into the formation at pressures and rates sufficient to create the desired large steam chamber without substantially mixing with the mobilized heavy oil. Pressures are usually within the range of about 50 to about 1500 psig, preferably 50 to 600 psig, during the oil recovery phase. Of course, initial injection pressures will preferably be much higher if the formation is to be fractured with steam pressure; generally during oil recovery the steam pressure may be 50 to 600 psig. For operation without a pump, sufficient pressure must be employed to allow the produced fluids to flow to the surface and into the production line. Lower pressures can be employed if a pump such as a conventional sucker rod pump or, preferably, a chamber lift pump is provided at the bottom of the well.

In many cases the choice of pressure will be controlled by an economic balance between two important factors: (1) the high rates achieved using high pressures and hence high temperatures and, (2) the lower steam consumption resulting from lower temperatures. In many cases a pressure near to the minimum for operation without a pump will be particularly attractive. Once a sizeable steam chamber has been established it is desirable to operate at pressures significantly below the fracture pressure.

Generally, in most field applications the steam will be wet with a quality of approximately 65 to 90 percent, although dry or slightly dry or slightly superheated steam may be employed so as to reduce the quality of injected water. An important consideration in the choice of wet rather than dry steam is that it may be generated from relatively impure water using simple field equipment. The quantity of steam injected will vary depending on the conditions existing for a given reservoir.

Experimental

A laboratory scale drainage experiment to model the invention disclosed herein has been carried out. The experiment is intended to duplicate, in a dimensionally scaled manner, an oil production system in which a horizontal well is situated along the fracture trend at a height of about 10 feet above the base of a reservoir of thickness 100 feet. A steam injection well is located above the horizontal well and parallel to it. As has been described previously, a vertical fracture is formed between the two wells and steam is introduced into the upper one. The laboratory model is a two dimensional scaled model of a cross-section perpendicular to the two wells. Its shape is shown schematically in Figure 7. The model reservoir was 4 3/8" high and 11 1/2" long. Thus, the 4 3/8" represents the vertical height (100 feet of the reservoir) and the 11 1/2" half of the horizontal distance between the pair of wells being considered and an assumed identical adjacent pair. Thus the right hand edge of the model represents a vertical plane of symmetry between the pair of wells in the model and those in the adjacent pattern.

A wire mesh was placed at the left hand edge of the model to represent the fracture in the reservoir. The model was 1" thick and filled with glass beads of a diameter chosen to suit the dimensional scaling criterion discussed below (8 mm). A steam inlet was connected near the top of the model and a production outlet at the appropriate distance above the bottom. For the three dimensional field case, these inlet and outlet ports each represent part of the long horizontal injection and production wells respectively.

A mathematical analysis of the flows assuming a drainage mechanism similar to that discussed previously was carried out to produce a scaling criterion. It was found that a dimensionless number B_3 was the same for the model as for the field then the flows would be geometrically similar. The appropriate dimensionless number is:

$$B_3 = \frac{\sqrt{kgH}}{\phi S_o \alpha \nu_s} \qquad (2)$$

B_3 is a dimensionless number which determines flow pattern.
m parameter in an equation approximating the change of oil viscosity with temperature:

$$\frac{\nu}{\nu_s} = \left(\frac{T_s - T_R}{T - T_R}\right)^m \qquad (3)$$

for Cold Lake crude, m is 3—4.

ν Kinematic viscosity at temperature T.
ν_s Kinematic viscosity at steam temperature T_s.
T_R initial reservoir temperature.
k Effective permeability of reservoir in ft².
g Acceleration due to gravity (ft/day²).
H Height of reservoir in feet.
ϕ Reservoir porosity.
S_o Recoverable saturation of oil.
α Thermal diffusivity (ft²/day).
ν_s Kinematic viscosity of crude oil at steam temperature T_s(ft²/day).

The use of this criterion allows scaling from laboratory to field situations even where the operating temperatures, as a result of different steam pressures, are different.

If the parameters for the model are chosen so as to give the same value of B_3 as for the field then time is scaled according to the following criterion.

$$T_3 = \frac{\alpha t}{mH^2}$$

where symbols are as before and T_3 is a dimensionless time number corresponding to t days.

If the dimensionless time number T_3 has a certain value for the model, then the fractional drainage at that time will correspond to that which would be expected at the time needed to give the same value of T_3 in the field case.

The use of this scaling approach will be apparent from the numerical data given in Table II. In this table two columns are shown; the first lists the parameters foo the model and the second for a corresponding field case. Since these two sets of parameters both give identical values of B_3 (1619) the flow patterns in the model will be geometrically similar to those in the field.

Table II
Comparison of Model & Field Physical Data & Dimensions

	Model	*Field*
m	3.9	3.9
kg ft^2/day^2	38100 (15000D)	2.54 (1.0D)
H ft.	0.34	100
ϕS_o	0.4	0.21
α ft^2/day	0.6	0.6
ν_s ft^2	131.9 (208°F)	4.87 (421°F) (312 psia)
B_3	1619	1619
T_3	1.29t	1.54×10^{-5}t

Ten minutes for the model is thus equivalent to $(10/60)(1.29/(1.54\times10^{-5}))=14000$ hours in the field or 1.6 years.

In summary, it is possible to construct laboratory models for gravity drainage experiments which will give geometrically similar performance to that in the field provided that the permeability of the laboratory model is chosen so as to give equivalent values to the dimensionless number B_3.

The laboratory model shown in Figure 7 was filled with Cold Lake crude oil by slowly flooding it through one of the ports. When it was completely full, it was cooled to room temperature. Steam was introduced into the steam inlet at atmospheric pressure. Condensate and oil ran from the production outlet. The course of the experiment could be followed visually since the two large surfaces of the model were made of transparent material. The position of the oil interface is shown at 10 minute intervals by the curved lines on Figure 7. It will be noted that drainage was continuous and that it provided a systematic way of removing essentially all of the oil. The cumulative drainage of oil is shown plotted as a function of time in minutes in Figure 8. Eighty percent of the oil drained in about one hour. It will be noted that there was a tendency for the rate to decrease as the experiment progressed which was due to the fact that the pressure head available to move the oil to the production well decreased as the reservoir became depleted. Also shown in Figure 8 is the time in years which would be required to drain the geometrically similar field example of Table II. In ten years it is predicted that about 80% of the recoverable oil would be removed.

Also shown in Figure 8 is a straight line which is the rate which would be predicted by the equation given previously. It will be noted that the rate from this equation is of the same order as the initial rate in the experiment, but that the equation does not predict the decline in the rate as the reservoir is depleted. It is however useful to estimate the initial rate and, if a reasonable allowance is made for the effect on depletion, it can also be used to estimate the overall course of the drainage process.

In the example shown, 80% of the ultimate recovery is predicted to occur in the field case in ten years. Thus, for a horizontal well system 1500 ft. long the average daily production can be predicted as follows:

$\phi S_o=0.21$ (recoverable)
$H=100$ feet (90 ft. above well)
Well Spacing$=100\times(11.5/4.375)\times2=526$ ft.
Oil recovered in ten years$=0.21\times90\times526\times1500\times0.8$
$=1.19\times10^7$ ft^3
$=2.1$ million barrels
Average daily production$=582$ barrels

The initial daily rate may be calculated from,

$$Q=0.0264\,L\sqrt{\frac{\phi S_o \alpha k g H}{m\nu_s}}$$

$$=0.0264\times1500\sqrt{\frac{0.21\times0.6\times1000\times90}{3.9\times5.24}}$$

$$=933 \text{ B/D}$$

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention. It should be understood that this invention should not be unduly limited to the specific embodiment set forth herein.

Claims

1. A process for mobilizing and recovering normally immobile oil from a tar sand deposit which is

penetrated by first and second wells, said first well being used for producing oil and said second well being used for injecting a heated fluid, which comprises:

(a) completing said first and second wells so that oil, when mobilized, flows substantially separate from said heated fluid;

(b) injecting said heating fluid into said second well such that thermal communication is established between said first and second wells;

(c) continuing to inject said heated fluid such that said normally immobile oil is heated and drains by gravity to said first well without substantially mixing with said heated fluid, said heated fluid expanding to fill that region of the deposit from which the mobilized oil has drained; and

(d) recovering the mobilized oil via said first well.

2. A method for recovering oil from a tar sand deposit, said oil being essentially immobile at normal reservoir temperatures, comprising:

(a) penetrating said deposit with a first well for injecting a heated fluid;

(b) penetrating said deposit with a second well for producing fluids, said first and second said wells being constructed and arranged so as to promote the growth of a heated fluid region in said deposit adjacent to said first well of greater than 30,000 ft^2 boundary surface area within about 365 days of initiating heated fluid injection;

(c) completing said second well so that a predetermined high saturation of oil is maintained adjacent to the lower portion of said second well during production;

(d) injecting heated fluid into said first well at a rate calculated to maintain said predetermined saturation and to produce said heated fluid region, said normally immobile oil draining by gravity towards said second well;

(e) producing said oil through said second well.

3. A method for recovering normally immobile heavy oil by gravity drainage from a subterranean formation which comprises:

(a) penetrating said formation with a production well having a substantially horizontal portion extending a substantial distance through said formation;

(b) penetrating said formation with a substantially vertical injection well located approximately above said horizontal portion;

(c) completing and operating said production well such that during production the liquid level in said production well is maintained above said horizontal portion;

(d) injecting heated fluid into said injection well such that thermal communication is established between said production well and said injection well;

(e) continuing the injection of heated fluid such that said heavy oil becomes mobile and drains by gravity to said horizontal portion and such that an expanding heated fluid region is created in said formation adjacent to said injection well without substantial mixing of said heated fluid and said mobilized heavy oil; and

(f) producing said mobilized heavy oil through said production well.

4. A method according to claim 3 wherein aqueous condensate from the steam flows towards said production well substantially separate from said mobilized heavy oil.

5. A method according to either of claims 3 and 4 wherein said heated fluid region has a boundary surface area of 30,000 ft^2 within about 180 days of the initial injection of said heated fluid.

6. A method according to any one of claims 3 to 5 wherein said heavy oil has an API gravity of about 13.5° or less.

7. A method according to any one of claims 3 to 6 which includes injecting said heated fluid into said production well so as to assist in establishing thermal communication between said production and injection wells.

8. A method according to any one of claims 3 to 7 wherein said injection well extends from about 5 to about 200 feet from said horizontal portion.

9. A method according to any one of claims 3 to 8 which includes locating said production wells substantially along the prevailing fracture trend of said formation and fracturing said formation prior to performing step (e).

10. A method for recovering viscous hydrocarbons from a subterranean formation, said hydrocarbons being substantially immobile at prevailing formation temperatures, the method which comprises:

(a) penetrating said formation with an injection well for injecting a heated fluid and a production well for producing hydrocarbons and condensate, said injection and production wells being located along the fracture trend of said formation;

(b) completing said wells such that, during production of hydrocarbons, a predetermined relatively high saturation of hydrocarbons can be maintained in the near-well region of said formation adjacent to the lower portion of said production well by regulating production rates;

(c) injecting steam into said first wellbore initially at fracture pressure or above to create a fracture fracture said formation, said viscous hydrocarbons being mobilized by said heated fluid and flowing to said production well along with any condensate;

(d) producing said mobilized viscous hydrocarbons at rates such that said predetermined saturation of hydrocarbons is established in said near-well region.

11. A method according to claim 10 wherein said injected fluid is steam.

12. A method according to claim 11 wherein said steam fills the portion of the reservoir that said hydrocarbons drain from to create an expanding steam chamber having a boundary surface area greater than 50,000 ft^2 within about 180 days.

13. A process according to any one of claims 1 to 12 wherein said heated fluid is steam.

14. A process according to any one of claims 1 to 13 wherein said normally immobile oil or viscous hydrocarbon when heated sufficiently to become mobilized, has a density greater than the condensate formed in said deposit.

15. A process for producing normally immobile bitumen from a tar sand deposit which comprises:

(a) penetrating said deposit with a first wellbore for injecting steam and a second wellbore for producing bitumen, said first and second wellbores lying along a fracture trend of said deposit;

(b) completing said first and second wellbore such that during the production of bitumen, a predetermined level of bitumen builds up in said second wellbore with throttled production, said level being calculated so as to assure that mobilized bitumen flows substantially separate from the steam injected into said deposit;

(c) injection steam into said first wellbore initially at fracture pressure or above to create a fracture between said wellbores, and continuing to inject steam to heat said bitumen thereby causing bitumen to become mobilized and to flow by gravity towards said second wellbore along with any steam condensate;

(d) producing said bitumen at rates which establish said predetermined level of mobilized bitumen in said wellbore.

16. A process according to claim 15 wherein non-condensable gases fractionate from said bitumen and said non-condensable gases are vented during oil production by means of said second wellbore.

17. A process according to claim 15 wherein non-condensable gases fractionate from said bitumen and said non-condensable gases are vented by means of another well completed to near the top of the formation.

18. A process according to either of claims 16 and 17 wherein said second wellbore is extended substantially horizontally through said deposit and said first wellbore extends substantially vertically into said deposit to a point near the horizontal portion of said second wellbore.

19. A process according to claim 15 which comprises completing said first and second wellbores such that, in the near wellbore region of said deposit, said mobilized bitumen flows substantially separate from any steam condensate which may form in the deposit.

20. A method according to claim 15 wherein a portion of said first and second wellbores extend substantially horizontally through said deposit in a substantially parallel relationship.

21. A method for recovering viscous hydrocarbons from a subterranean reservoir which comprises:

(a) penetrating said reservoir with a substantially vertical production well and a substantially vertical injection well, said wells located in line with the fracture trend of said reservoir;

(b) completing said production well such that, during production, a predetermined level of hydrocarbons is ensured in the lower portion of said production well;

(c) fracturing said reservoir to establish a path of thermal communication between said injection and production wells;

(d) injecting steam into said injection well to heat and mobilize said viscous hydrocarbons, said mobilized hydrocarbons draining by gravity to said production well along said thermal communication path and building up to said predetermined level, said predetermined level being calculated to promote flow of the mobilized hydrocarbons without substantial mixing with injected steam;

(e) producing the mobilized hydrocarbons and steam condensate via said production well so as to maintain said predetermined level of hydrocarbons.

22. A method according to any one of claims 15 to 21 wherein steam is used to fracture said formation.

23. A method according to claim 22 wherein said steam is injected at high pressure.

24. A method according to claim 23 wherein after said reservoir is fractured, the pressure of the injected steam is reduced to a value substantially lower than fracture pressure.

25. A method according to any one of claims 1 to 9 and 15 to 21 wherein said reservoir is fractured with a hydraulic fracturing fluid.

26. A method according to claim 25 wherein said fracturing fluid contains a proppant.

27. A method for recovering hydrocarbon from a subterranean formation according to any one of claims 1, 2, 3, 10, 15 and 21 substantially as hereinbefore described with reference to the drawings.

28. Hydrocarbon whenever recovered from a subterranean formation by a method according to any one of the preceding claims.

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Alberta OIL SANDS INFORMATION CENTRE

United States Patent [19]

Allen

[11] **4,257,650**

[45] **Mar. 24, 1981**

[54] **METHOD FOR RECOVERING SUBSURFACE EARTH SUBSTANCES**

[75] Inventor: **Joseph C. Allen**, Bellaire, Tex.

[73] Assignee: **Barber Heavy Oil Process, Inc.**, Houston, Tex.

[21] Appl. No.: **940,390**

[22] Filed: **Sep. 7, 1978**

[51] **Int. Cl.**³ **E21B 43/24**; E21C 41/10

[52] **U.S. Cl.** **299/2**; 166/50; 166/245; 166/263; 166/303

[58] **Field of Search** 166/245, 263, 272, 302, 166/303, 50, 57, 62; 299/2, 3, 4, 5, 6

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Assistant Examiner—George A. Suchfield
Attorney, Agent, or Firm—Bard & Groves

[57] **ABSTRACT**

This invention relates to methods and systems for recovering high viscosity oils, petroleum substances and other minerals from subsurface earth formations. In particular, one or more large diameter shaft holes are provided which preferably terminate in an enlarged subterranean chamber. A plurality of drill holes are provided, with perforated piping which extend radially from the chamber into the formation, and from which oil and the like may be recovered. It is a particular feature of this invention to provide means and methods for injecting a mixture of steam and a noncondensable gas into the drill holes, whereby the driving mechanism of the formation may be selectively maintained or enhanced at the same time the viscosity of the oil in the formation is reduced.

9 Claims, 9 Drawing Figures

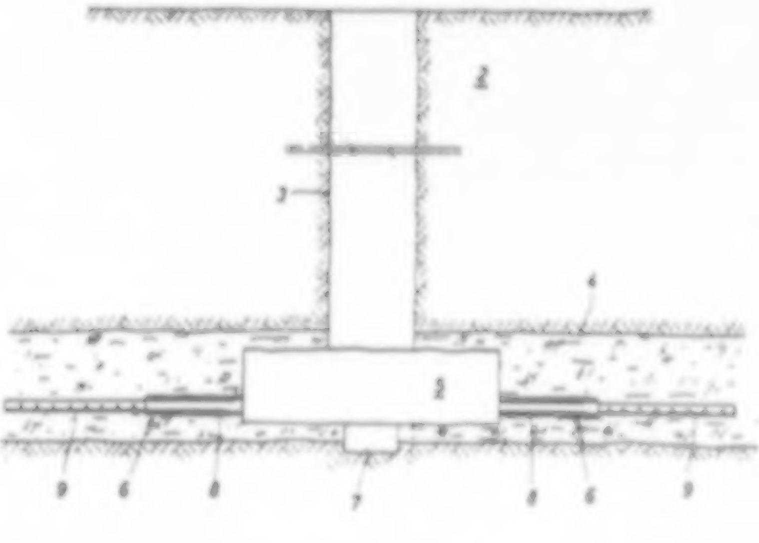
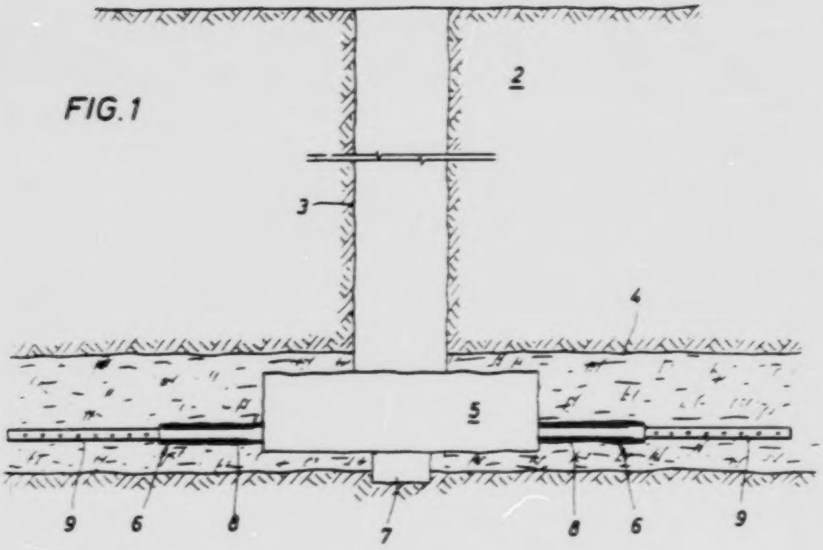


FIG. 1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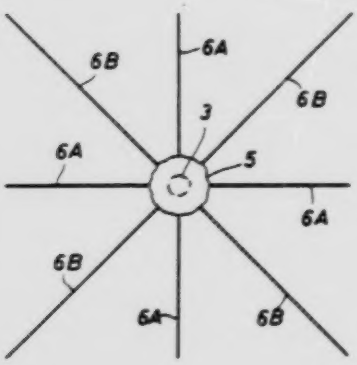
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FIG. 2

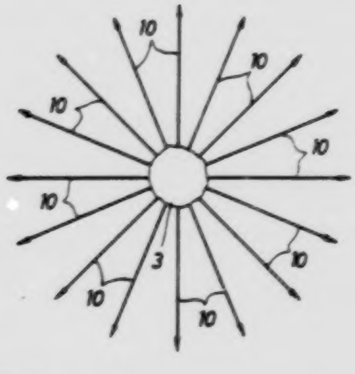
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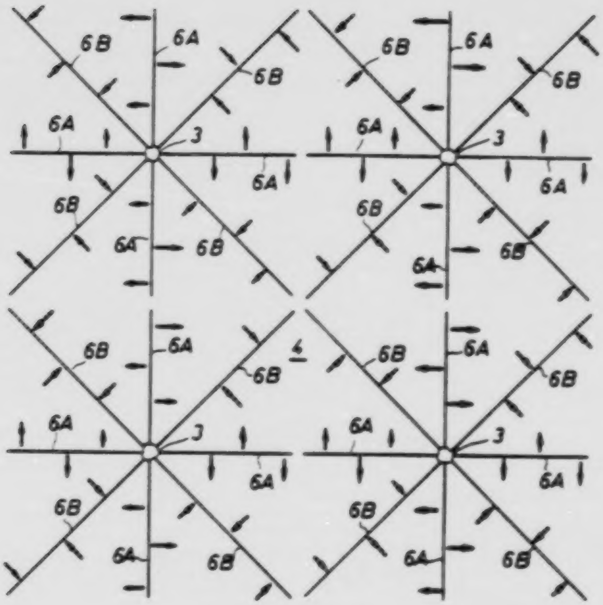
FIG. 4

FIG.3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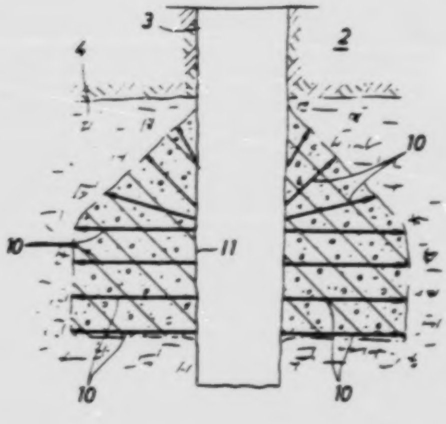
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FIG.5

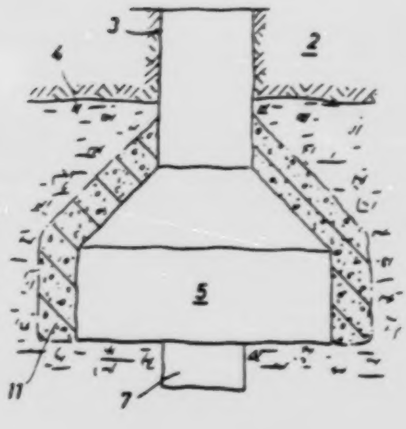


FIG.6

FIG. 7

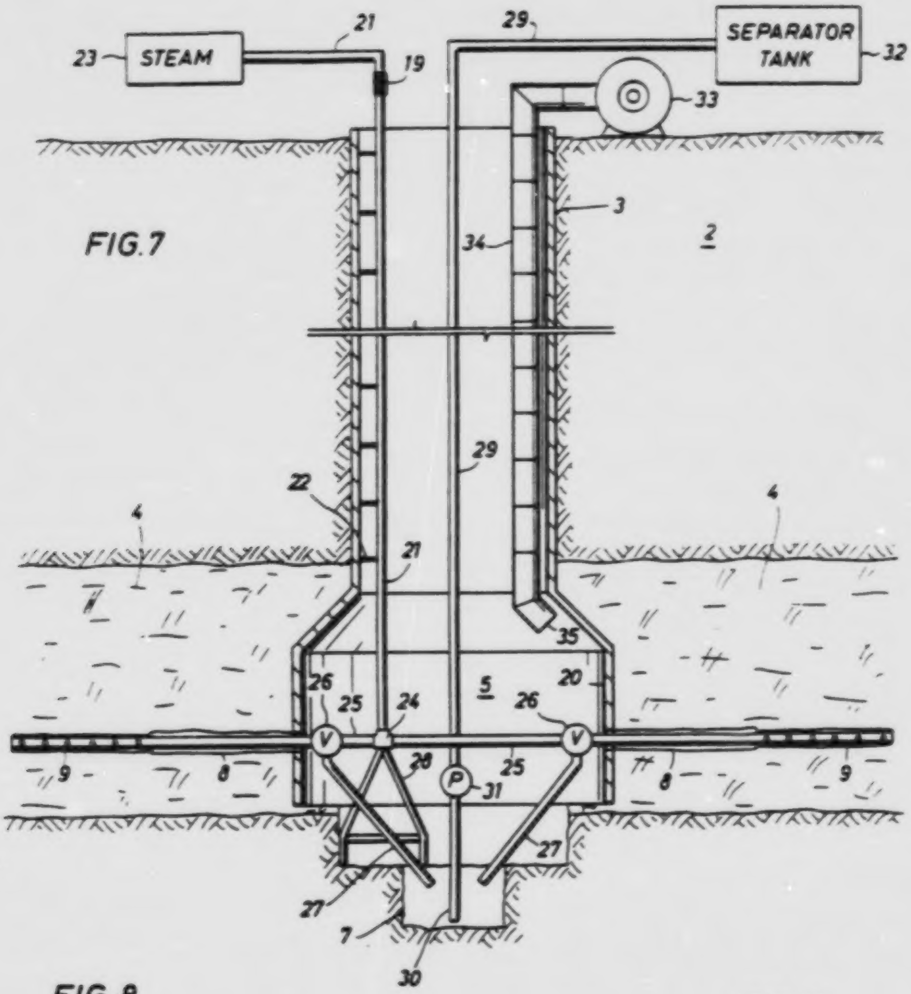

23
STEAM
21
19
29
SEPARATOR TANK
32
33
3
34
2
29
22
4
21
4
35
20
5
26
25
24
26
25
28
31
9
8
8
9
27
27
7
30

FIG. 8

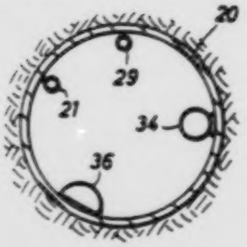
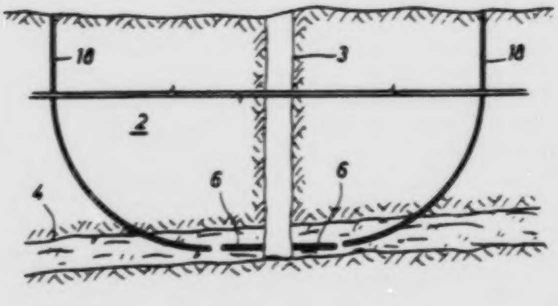

20
29
21
34
36

FIG. 9



METHOD FOR RECOVERING SUBSURFACE EARTH SUBSTANCES

BACKGROUND OF THE INVENTION

This invention relates to methods for recovering minerals from subsurface earth formations, and more particularly relates to improved methods for recovering high viscosity oil.

It is well known to pump steam into a vertical borehole and laterally into the formation in order to heat the oil in the formation to render it less viscous and in order to produce a driving force to move the oil to other recovery wells. It has been found in such steam flood operations that the driving force provided by the steam will collapse when the temperatures in the formation fall below the boiling point of water. In order to avoid this driving force collapse, inert or noncondensable gases have been added to the steam in order to enhance and maintain an oil-driving force within the formation.

Steam flood techniques may also be applied to what is termed horizontal wells. In horizontal wells, laterals protrude into the formation from a mine shaft and steam is introduced into the laterals in order to provide heat to the formation for reduction of the oil viscosity and to produce a gas cap of steam which functions as a driving force to move the oil.

What is not known in the prior art and what constitutes the features and concepts of the present invention is the use of a mixture of steam and an inert gas in a horizontal well. As noted above, various attempts have been made to recover oil in a vertical well by employing a mixture of steam and an inert or noncondensable gas. For example, in U.S. Pat. No. 3,908,762, a complex steam injection process is depicted which employs a mixture of steam and a noncondensable gas and wherein significance is primarily based upon the disclosure that the noncondensable gases may include nitrogen, air, CO_2, flue gas, exhaust gas, methane, natural gas, and ethane.

An early disclosure relating to the horizontal well concept is provided in a paper published by Ranney in the *Petroleum Engineer* in 1939 entitled "The World's First Horizontal Hole". The article proposes the drilling of a shaft into an oil-bearing formation and then drilling radial horizontal laterals into the formation. Air, gas, or steam is disclosed as a possible fluid injection medium. However, there is no reference to the use of a mixture of steam and an inert gas as an oil recovery medium.

The above described prior art techniques, however, are each subject to disadvantages which are sought to be avoided with the method of the present invention. For example, the process depicted and described in U.S. Pat. No. 3,908,762, suffers limitations relating to critical velocity concepts to be described hereinafter, as well as limitations due to restrictions on critical injection rate. The Ranney process also suffers from limitations due to the inefficiency of the pressure medium as a driving force.

As will be hereinafter set forth, in more detail, such disadvantages are overcome by the present invention.

SUMMARY OF THE INVENTION

In an ideal embodiment of the present invention, a vertical mine shaft or the like is bored or dug from the surface to the formation of interest, whereby personnel and equipment can reach the face of the formation.

More particularly, the portion of the borehole across the formation is preferably enlarged laterally so as to provide a work chamber of a shape and size sufficient to permit operations to be conducted at the face of the formation in an appropriate manner, subject to whatever shoring may be required under particular conditions. Thereafter, drill holes are bored into the face of the formation and radially about the chamber, through which a suitable fluid is thereafter injected into the formation by way of a conduit leading to the surface.

The particular spacing and arrangement of drill holes will, of course, depend upon the size and lithology of the formation of interest, but it is a feature of the invention to provide approximately eight different radially extending drill holes for each shaft hole, and to further extend such drill holes to a location adjacent the ends of similar radials extending from an adjacent vertical shaft hole. As will hereinafter be explained in detail, each group of radial drill holes will then define a rectangular pattern within the field, and thus the field may be effectively "covered" with a blanket of such rectangular patterns. The radials themselves will usually extend in a generally horizontal direction, although it may be preferable to extend the radials along the lateral axis of the formation. Alternatively, the radials may be positioned at a slight upward angle relative to their respective shaft hole in order to accommodate gravity flow of the oil from the formation.

It is within the concept of the present invention to locate the radials adjacent the lower limit of the formation, whereby the fluid injected therefrom will also tend to rise as well as travel laterally through the formation, and also to provide additional pluralities of such radial drill holes at other higher locations within thicker formations, whereby the formation adjacent the shaft hole may be more effectively heated. Furthermore, it is within the concept of this invention to inject fluid through only a portion of the radials, while also recovering oil from one or more of the other radials extending from the same shaft hole. Thus, the minerals of interest which are relatively adjacent such shaft holes may be more effectively recovered, as well as providing better control over the pattern of sweep flow through the overall field.

As noted above, the central concept is, of course, a steam injection or flood technique wherein a mixture of steam and an inert gas (such as flue gas, air and the like) is injected into the formation, rather than steam only.

One of the major problems encountered in conventional recovery techniques in vertical wells, and in particular wherein steam only is injected into the formation, is that such techniques must take into consideration an operating factor commonly referred to as the "critical velocity" at which the fluids move through the formation matrix, in order to effectively approach or achieve the maximum volumetric sweep efficiency of the formation of interest. The way this is usually done, however, is to operate the process or technique with respect to that steam injection rate which is most nearly effective to achieve the "critical velocity" for the particular formation of interest, and which is therefore beneficial in a horizontal well in accordance with the particular installation.

If the steam is injected at a rate which is either greater or less than the "critical injection rate" for the particular formation sought to be produced, the result will be that fluids will be produced from formation at less than the production rate which can be achieved with this critical injection rate. Further, the total amount of fluids recovered may be substantially below that which is possible by achieving and maintaining steam injection at the critical rate.

The volumetric sweep efficiency of a formation is dependent upon many factors such as its porosity, the viscosity of the oil therein, and the homogeneity of the rock matrix. Accordingly, the critical injection rate of the operation will therefore also depend upon these and other factors which may vary significantly between different installations. Nevertheless, in most if not all conventional steam injection operations it is a primary objective to determine this critical injection rate, and to thereafter hold to that factor as closely as possible.

This concept of critical velocity can best be explained by visualizing a cross-section of a given formation reached by a vertical borehole. When conventional steam recovery operations are initiated, steam is injected into the formation in an attempt to heat the oil and to drive it laterally into an adjacent recovery well. A maximum volumetric sweep efficiency would exist if it were possible to permeate the steam across the entire cross-section of the formation and move the steam laterally as a front. Thus, ideally this steam front would proceed as a vertical wall from the borehole uniformly across the formation and thereby force all of the oil in the formation out ahead of it and into an adjacent recovery well. The steam in this case would be functioning akin to a piston driving away all oil lying in its path of travel.

Practically, this piston action of steam in a vertical well is not possible due to formation anomalies and the phenomena known as fingering and gravity override.

In the case of fingering, the steam ruptures the interface and penetrates into the formation without displacing any significant quantity of oil. In the case of gravity override, the steam rises directly to the top of the formation and, thereafter, passes out through the formation over or above substantially all of the oil sought to be displaced.

Fingering is accentuated by high steam injection rates which produce a plurality of laterally extending paths of steam flow that jut across the formation and into the recovery well. These finger-like steam flow paths displace very little oil and merely vent through to the recovery well as waste steam. Obviously, then, steam fingering is an undesirable result from the standpoint of heat loss and reduction of the steam driving force.

According to conventional techniques, there is always the pressing need of maintaining the injected steam at the critical injection rate to achieve maximum volumetric sweep efficiency. Low steam injection rates fail to maintain an efficient driving interface and a low volumetric sweep efficiency results. Abnormally high injection rates of steam are most likely to produce fingering.

This limitation of critical velocity is overcome in the present invention, however, because fingering is not a significant factor in a horizontal well of the type depicted herein. In particular, fingering of the steam which prevents the maximum volumetric sweep efficiency in a vertical well from being achieved may actually be beneficial to the present invention. This is for the reason that if fingering does occur in the process of this invention it merely adds to the gas cap above the formation without significantly detracting from the efficiency of the steam sweep. This is peculiar to the concept of a horizontal well, since the horizontal well benefits from a gas cap above the formation as the driving force. Thus, if fingering does occur the escaping steam builds up the overlying gas cap rather than vent to a recovery well as is the case with conventional vertical wells.

Fingering can be tolerated in a horizontal well of the type herein described. It follows, therefore, that the steam may be injected at rates far above the critical injection rate which as noted above is detrimental in conventional vertical wells.

Gravity override will always occur when the density of the injected fluid is less than that of the formation fluids, and there is at least some vertical permeability in the formation, which factors are always present in all steam injection operations. Furthermore, it is known that the addition of an inert gas to the injection fluid will accentuate this detrimental phenomenon, since the inert gas will tend to lift the driving fluid mixture within the formation, and to thereby enhance the effect of gravity override.

Because the present technique does not employ a vertical driving fluid/oil interface, gravity override of such an interface cannot occur. In fact, the natural lifting effect of the inert gas will be of benefit to the present operation.

Conventional vertical wells sought to be produced by steam injection have long suffered from another drawback of driving force collapse. More particularly, at formation temperatures below the boiling point of water, the steam condenses with the result that little driving force is available to sweep the oil from the formation. In fact, condensation of the steam driving force can create a pressure drop in the formation which, in turn, results in a reverse effect. This is occasionally sought to be overcome by the addition of an "inert" (non-condensing) gas to the steam being injected into the formation, for the purpose of preventing or mitigating the pressure collapse when the temperature of the injected mixture drops below the boiling point of water in the formation.

This has not proved to be altogether satisfactory, however, since the heat carrying capacity of the inert gases is much lower than that of steam, and therefore only very limited proportions of inert gases could be tolerated in vertical well recovery operations. Too high a proportion of inert gas to steam resulted in a driving force mixture that did not carry enough heat into the formation to reduce the viscosity of the oil in order to enhance the sweep. Also, as previously explained, the inert gas increased the chances of gravity override. Conversely, too low a proportion of inert gas to steam resulted in a driving force mixture which when the steam collapsed contained too small an amount of inert gas to function significantly as a driving force. For conventional vertical wells, the addition of inert gas to a fixed steam at the critical velocity would accentuate viscous fingering and gravity override, thereby exceeding the critical velocity, thereby reducing volumetric sweep effeciency.

Such disadvantages are not, however, inherent in the horizontal well of the present invention and the drawbacks of the prior art are avoided. In particular, the constant balancing and counterbalancing of the ratios of steam to inert gas, in conventional operations, is not required in operations employing the present invention. This is for the reason that this invention operates at injection rates far above those rates employed in conventional vertical wells. Since higher injection rates can be utilized in the present invention—even to the point of tolerating steam fingering—these higher injection rates amply supply sufficient heat to the formation even when the inert proportion is high, and amply provide sufficient driving force if and when the inert gas proportion is low.

While the prior art discloses horizontal steam injected wells, in particular Ranney referred to herinabove, it is only a casual disclosure. For example, the prior art in the field of horizontal well technology does not disclose the concept of totally disregarding the critical velocity as a factor in oil recovery. Further, horizontal well technology failed to realize the advantage disclosed herein of employing a mixture of steam and a noncondensable inert gas for oil recovery operations in a horizontal well. More is involved herein than merely substituting concepts from conventional vertical well recovery technology into the unique operation of a horizontal well, since as noted above, the two are antithetical for all practical purposes.

PREFERRED EMBODIMENT

Although the methods and apparatus of the present invention are suitable for the recovery of both inorganic and organic minerals, an embodiment of the invention is especially suitable for recovering high viscosity oil and the like. More particularly, the subject formation is penetrated by a plurality of large diameter shaft holes, as hereinbefore described, and a plurality of eight equally spaced apart drill holes are then drilled radially outwardly therefrom into the formation at distances such that the radials then define a rectangular pattern within the field.

A mixture of steam and inert gas is injected into the radials for a first discrete time interval depending upon the thickness and other lithological characteristics of the formation, and then the wells are "shut in" to trap the steam mixture in the formation during a second discrete time interval, after which the radials are again opened for a third discrete time interval to allow the oil to enter the shaft well through the radials and be pumped to the surface. This completes a single steam-soak cycle. This "soak" technique is then repeated during one or more subsequent cycles, whereby the steam and inert gas mixture not only tends to penetrate further into the formation with each injection, but wherein the oil lying within the portion of the formation being soaked is caused to be heated gradually to the temperature sought to be achieved.

After the formation has been treated sufficiently by the "soak" technique, as thus described, the steam mixture may then be injected continually into some or all of the radials extending from selected shaft holes, while the remaining radials extending from the same or other shaft holes are opened to receive oil from the formation. Thus, the steam mixture is caused to sweep into the formation and across the field, to thereby more effectively produce the oil contained therein.

In conventional steam injection processes, wherein steam is injected into the top of a perforated steel well casing, the steel casing tends to drain away substantial amounts of heat sought to be applied to the formation. Since, in this embodiment of the invention, the radial drill holes through which the steam mixture is injected lie entirely within the formation, heat loss by way of the steel casing therein is not significant since the heat merely transfers to the formation sought to be heated. On the other hand, it is desirable for the steam mixture to enter the formation at a distance from the shaft hole or chamber, so that the steam mixture will tend to move outwardly therefrom instead of bypassing back into the chamber, and so it may be preferable to provide perforations or vents only in the outer or further portions of the casing within the radial drill holes. Furthermore, it may be preferable to insert pre-perforated pipe or casing into the radial drill holes, rather than to perforate the casing in a conventional manner after it has been inserted.

In another feature of the present invention, it should be noted that the sweep pattern or configuration of the steam mixture injected into the field is a function of the location and spacing of both the shaft holes and the radial drill holes. In addition, the size, spacing and position of the perforations in the pipe or casing inserted in these lateral drill holes will also determine the pattern or configuration of the steam mixture sweep in the formation.

A particular feature of the present invention is that the steam mixture is not only injected directly into the formation without heat loss through the conventional well casing, but that the heat emanating from the injected steam mixture is more effectively transferred to the oil within the formation. Accordingly, the effectiveness of the present invention is less dependent upon the permeability and other lithological characteristics of the formation than is the case with the methods of the prior art.

Another feature of the present invention is that the drill holes radially extending from the shaft holes may be selectively sized and positioned so as to more effectively sweep the formation with the steam mixture during the flood sequence than is the case with the methods and practices of the prior art, and whereby production of this type of oil is maximized.

Thus, a particular advantage of this invention is its use as an in situ process for reducing the viscosity of so-called "heavy" oil in subsurface earth formations, whereby such oil may be recovered. It is admittedly old to inject steam into an oil-bearing formation to reduce the viscosity of such oil. Furthermore, it is admittedly old to drill a large-diameter mine shaft into an oil-bearing formation and to thereafter recover such oil through a plurality of drill holes extending radially outward from the mine shaft into the formation. Finally, it is admittedly old to inject steam into such an array of lateral drill holes, but using conventional steam injection techniques and for conventional purposes only.

In the present invention, the process is not merely injection of steam and inert gas into lateral drill holes extending radially into the formation from a mine shaft and the like but to employ a sequence of alternate "injection" and "soak" intervals for the purpose of trapping an increasing amount of heat and pressure within an expanding areal portion of the formation. When the technique is practiced in the proper manner as explained in the instant patent application, the oil or bitumen or the like is not only rendered less viscous to an increasing degree, the treated oil is then caused to be moved through the formation to a selected borehole or collection point by the increased formation pressure also being developed.

As will be apparent from a full understanding of the present invention, this simultaneous reduction in viscosity and increase in formation pressure is not to be achieved effectively using conventional steam injection techniques. In the first place, it is important that the steam and inert gas be injected effectively into and throughout a substantial areal portion of the formation, and this is substantially impossible without the use of the type of laterally extending drill or boreholes which are positioned as radials from a mine shaft or the like. In the second place, however, it is desirable to hold the formation under pressure during appropriate intervals to let the heat from the steam and inert gas mixture permeate through an increasing portion of the formation.

In other words, to effectively use this process, the steam-inert gas may be injected into the formation during a limited or discrete "injection" interval to achieve a pre-selected pressure within the formation, and that each such injection interval or cycle may be followed by a "soak" cycle during which the steam and inert gas then in the formation is trapped to cause the formation to be literally soaked with heat. The process contemplates a repetitive series of such cycles, of course, not only to gradually effect permeation of a large portion of the formation with enough heat to reduce the viscosity of a substantial amount of oil, but also to move such oil through the formation to the collection point or well.

As noted above, prior art techniques are subject to many disadvantages. In the case of conventional vertical wells using steam injection to recover high viscosity oil and the like, it should be noted that the formation is contacted by steam only at the interface between the formation and the borehole, and this tends to restrict the input rate of steam laterally into the formation. Even more serious, conventional vertical well steam injection techniques often require as many as ten or more injector wells for each twenty-five acres of area, and heat losses by way of the steel well casings are accordingly substantial. In addition, steam injected into the formation through a conventional vertical borehole will often override the oil in the formation and travel directly to the producing wells. Even more particularly, when the temperature of the steam drops below the boiling point of water, the resulting condensation of the steam into minute droplets of water tends to produce a collapse of the driving force sought to be applied to the oil in the formation.

If the formation is injected with heated noncondensable gases such as hydrogen, nitrogen, etc., this driving force will continue to be exerted regardless of the particular temperature of the injection gas. However, noncondensable gases have a relatively low heat capacity, and therefore do not transmit heat to the formation as effectively as steam. Moreover, there is an even greater tendency for noncondensable gas to rise to the top of the formation, and to accordingly by-pass the oil therein, especially when the formation contains a fissure or other internal discontinuity.

Recently, an improved steam injection technique has been disclosed which is described in U.S. patent application Ser. No. 766,523, which was filed Feb. 7, 1977 now U.S. Pat. No. 4,160,481, by L. Jan Turk and Ralph D. Kehle, and which overcomes or alleviates certain of the more troublesome disadvantages of the prior art. In particular, this new technique disclosed the use of a large diameter shaft hole in lieu of the conventional drill hole, with an enlarged work chamber located at the bottom of the shaft hole and adjacent the face of the formation of interest. More particularly, drill holes are then bored into the face of the formation so as to extend as radii from the work chamber and laterally into the formation, whereby steam injected into these laterally radiating drill holes will more effectively and deeply permeate the formation of interest. In addition, this new steam injection technique contemplates that steam will initially be injected during a discrete "injection" cycle, whereupon the radial drill holes will be stoppered to trap the injected steam within the formation for a further "soak" cycle of discrete duration before production from the formation is attempted.

As hereinbefore stated, this new Turk et al technique, which may be repeated for successive "injection" and "soak" cycles before production is attempted, will be seen to have significant advantages over the prior art. In particular, heat loss by way of the well casing is substantially eliminated since the injection wells lie entirely within the formation of interest. Furthermore, steam injection with this technique achieves much greater volumetric sweep efficiency since the radial drill holes can be located at the bottom edge of the formation, and since they tend to introduce steam into the formation at points deep within the formation itself. On the other hand, steam injected by this new process will nevertheless condense when its temperature drops to the boiling point of water, which generates a collapse of driving pressure within the formation. Furthermore, this particular phenomenon is especially troublesome in view of the fact that an objective of the "soak" cycle is to enhance formation pressure as well as to heat the oil trapped therein.

It is a particular feature of the present invention to recover oil from the same drill hole or holes which are used for injecting the heating mixture into the formation. What is of special significance, however, is that the driving mechanism for the oil is the pressure induced into the formation by the injected heating fluid, rather than gravity flow as may heretofore have been expected.

The primary if not sole purpose of injecting steam into the formation, in any steam-injection operation, is to effect heat transfer into the oil in the formation, and is only secondarily to enhance the pressure in the formation. This is because steam will hold more heat than any of the inert gases contemplated for this invention. On the other hand, the primary purpose of injecting an inert or non-condensible gas into the formation is to enhance formation pressure, and is only secondarily to effect heat transfer into the oil.

Accordingly, it is a particular feature of the present invention to inject a substantial quantity of inert or non-condensible gas into the formation, either simultaneously with injection of steam, or in conjunction with separate injection of steam according to a preselected sequence. For example, the "soak" cycle of the operation may comprise injection of a heating fluid which may be predominately or entirely composed of steam, followed by a discrete shut-in period during which the injected fluid is trapped in formation. Thereafter, the process may conveniently include an additional step wherein the formation pressure is enhanced by injection of an additional fluid which may be predominately or entirely composed of a non-condensible gas, before the injection boreholes are again opened to provide for recovery of oil from the formation.

This particular sequence, wherein the "soak" cycle is followed by a "pressuring" cycle, before recovery is attempted, may even be repeated one or more times before the wells are opened for production. Alternatively, the injection fluid used to heat the oil, or even to pressure the formation, may conveniently include a solvent and/or other materials such as a surfactant and the like.

For these reasons, it is a feature of the present invention to provide a novel method of recovering oil and the like from subsurface earth formations, comprising the steps of drilling a borehole substantially laterally into said subsurface earth formation, injecting a heating fluid comprising steam into said borehole during a first discrete time interval for transferring heat to oil in said formation, thereafter injecting a pressurizing fluid into said borehole during a second discrete time interval for creating a pressure on said oil in said formation and withdrawing oil from said borehole in response to said pressure created in said formation during a third time interval following said first and second intervals.

It is another feature of the present invention to provide an improved method of recovering oil and the like from a subsurface earth formation, comprising the steps of establishing a shaft hole extending from the surface of the earth to a formation of interest and having a cross-sectional size accommodating passage of personnel therethrough, enlarging said shaft hole laterally within said formation to establish an operating chamber connecting said shaft hole with said formation, drilling a plurality of boreholes radially extending from said chamber into said formation, injecting a fluid mixture of steam and an inert gas through at least one of said boreholes and into said formation, and thereafter withdrawing said mineral from said formation.

These and other features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

IN THE DRAWINGS

FIG. 1 is a simplified pictorial representation partly in cross section of a portion of an exemplary installation for recovering oil from a subsurface earth formation according to the concepts of the present invention.

FIG. 2 is another different functional representation of the installation suggested in FIG. 1.

FIG. 3 is a simplified functional representation of the overall installation suggested in FIGS. 1 and 2.

FIG. 4 is a simplified functional representation of a stage in the construction of the installation suggested in FIGS. 1–3.

FIG. 5 is another simplified functional representation of another stage in the construction of the installation suggested in FIGS. 1–3.

FIG. 6 is a further different functional representation of a third stage in the construction of the installation suggested in FIGS. 1–3.

FIG. 7 is a more detailed pictorial representation, partly in cross section, of certain mechanical features of the installation suggested in FIGS. 1–3.

FIG. 8 is another view of the installation sought to be depicted in FIG. 7.

FIG. 9 is another simplified functional representation of an alternative installation embodying the concepts of the present invention.

DETAILED DESCRIPTION

Referring now to FIG. 1, there may be seen a simplified pictorial representation of one type of system embodying the concepts of the present invention for recovering heavy oil and the like from a subsurface earth formation, and depicting a substantially vertical mine shaft 3 or the like drilled from the surface of the earth 2 to and into a subsurface earth formation 4 of interest. More particularly, it may be seen that the shaft 3 is drilled completely through the formation 4, and is thereafter excavated laterally within the formation to provide a work chamber 5 with a sump hole 7 in the floor of the chamber 5 immediately below the lower end of the shaft 3. As may be seen in FIGS. 1 and 2, the radial lines 6 are thereafter drilled into the earth formation 4 from the wall of the chamber 5, preferably at or adjacent the lower limits of the formation 4.

Referring again to FIG. 1, it may be seen that the portion of the radials 6 extending from the wall of the chamber 5 may be suitably provided with so-called "surface" casing 8, with the outer end of the casing 8 thereafter provided with pre-perforated drain line pipe 9. The walls of the shaft 3 may be conveniently sealed with sections of bolted or welded steel plates to form the casing 20, as hereinafter depicted in FIG. 7, or it may be lined with an appropriate material such as Gunite, to prevent caving or other collapse of the walls of the shaft 3. The diameter of shaft 3 is preferably of a size sufficient to accommodate the passage of men and equipment from the surface of the earth 2 to the interior of the work chamber 5. Accordingly, the shaft 3 may be constructed by various conventional means, such as by drilling with a large diameter auger (not depicted), or by conventional excavation, depending upon the character of the various strata of the earth 2 lying above the formation 4 of interest.

Referring now to FIG. 7, there may be seen a more detailed pictorial representation of the installation functionally represented in FIG. 1, and showing that the shaft 3 has been underreamed or enlarged to provide the chamber 5, and then has been provided with a steel liner 20 throughout the length of the shaft 3 and the walls of chamber 5. More particularly, surface equipment is represented as including a source of live steam 23 or other heating means such as a mixture of steam and an inert gas explained more fully hereinafter, and having its discharge line 25 extending down to the chamber 5 to a junction 24 having lateral lines 25 interconnected with each radial 6 by means of a two-way control valve 26. The line 21 may conveniently be supported in the shaft 3 by means of a plurality of brackets 22 interconnecting the lines 21 to appropriate locations along the length of the steel line 20, and the assembly composed of the line 21 and junction 24 may be further supported within the chamber 5 by a suitable support assembly 28 positioned on the floor of the chamber 5.

Referring again to FIG. 7, it may be seen that the installation also includes an oil collection line 29 having its lower intake portion 30 positioned at or adjacent the bottom of the sump 7, and having its upper end running to the surface of the earth 2 for interconnection with a conventional separator tank 32, with the usual assembly of tank batteries and other apparatus not specifically depicted in FIG. 7. As will hereinafter be explained in detail, oil is intended to be accumulated in the sump 7, and thus the collection line 29 is preferably provided with a suitable pump 31 for lifting oil from the sump 7 through the collection line 29 to the separator 32 and other surface equipment.

Referring again to FIG. 7, it will be apparent that if personnel are expected to operate within the chamber 5 for any extended period of time, ventilation of the interior of the chamber 5 is required. Accordingly, an air line 34 is preferably extended down through the shaft 3, with its upper end connected to an appropriate blower

33 at the surface, and with its lower discharge vent 35 appropriately positioned within the chamber 5. In addition, a caged or shield ladder 36 or other suitable means may be included to permit workmen to enter and depart from the chamber 5.

It will be apparent that both the oil collection line 29 and the air line or duct 34 must also be supported within the shaft 3. Accordingly, and as more particularly suggested in FIG. 8, it will be seen that the oil line and air duct 34 may also be connected to the steel liner 20 by appropriate brackets in the same or substantially the same manner as hereinbefore stated with respect to the line 21.

Referring again to FIG. 7, it may be seen that the installation depicted therein is arranged primarily to inject a steam mixture from its supply 23 through the line 21 to and into each conductor casing 8 and drain line 9 within the formation 4. Such injection may be continued for a preselected length of time such as three to four weeks. After the steam mixture injection has been terminated, the entire areal portion of the formation 4 will preferably be allowed to "soak" for an additional period, such as a week, during which the heated oil within the formation 4 should experience further reduction of its viscosity. Thereafter, the valve 26 for each radial line 6 is changed to its alternate position, whereby the steam mixture from the line 21 is interrupted, and wherein oil from the formation 4 may then drain into the perforated drain lines 9, and through the conductor casings 8 and valves 26 to discharge pipe 27 extending from each valve 26 and into the sump 7. Upon accumulation of a sufficient quantity of oil within the sump 7, the pump 31 may be activated to lift the oil through the collection line 9 to the separator tank 32 as hereinbefore stated.

It has been determined that the practices hereinbefore described will require at least one such installation for an area of approximately one million square feet, or approximately twenty-three acres, of the formation 4 of interest. Accordingly, and as more particularly depicted in FIG. 3, it will be seen that the present invention is more profitably employed by installing a plurality of such installations, and by operating such installations in a simultaneous manner, whereby the entire field can be drained in a systematic manner.

Referring now to FIGS. 4–6, there may be seen an illustration of various stages in the construction of the system hereinafter described. In particular, the shaft 3 is first drilled or excavated to an appropriate depth, and is thereafter lined with steel casing 20 as hereinbefore explained. However, the portion of the shaft extending across the formation 4 is preferably provided with sections of casing 20 which are bolted together, rather than being welded, and are further provided with appropriate holes for drilling six to ten-foot long grouting holes 10 into the formation. After the grouting holes 10 are completed, concrete is injected into the earth by an appropriate grouting machine (not depicted) which will be located within the bottom of the excavated shaft 3. After a concreted area 11 has been provided as suggested in FIGS. 5 and 6, the bolted steel casing may be removed, and the chamber 5 may then be constructed by excavation in a conventional manner.

Referring again to FIG. 3, it will be noted that the length of the radials 6 will depend upon their relative position to each other, since it is intended that the radials function to eject a steam mixture in a uniform manner throughout a substantial portion of the formation 4. Accordingly, it is assumed that the area to be covered by each shaft 3 will be approximately twenty-three acres in extent, four of the radials 6 will be approximately 490 feet long, and four of the radials 6 will be approximately 690 feet long.

The position of the radials 6 within the formation 4 will usually depend primarily upon the character of the substance sought to be recovered. If the mineral is high viscosity oil, then the radials 6 will usually be aligned along and adjacent the lower side of the formation 4, even if the formation 4 lies at an angle with respect to horizontal, since the internal pressure within the formation 4 will drive the oil through the radials 6 and into the shaft 3. If the mineral of interest is salt, sulfur, or a metallic ore or the like, it may be convenient to extend the radials 6 in a horizontal direction from the shaft 3, and even tilted upwardly at a small angle, to facilitate gravity flow therethrough.

The diameters of the radials 6 will depend primarily upon the type of matrix composing the formation 4, as well as upon the viscosity of the oil sought to be recovered therefrom. The steam mixture line 21 is preferably provided with insulation material such as asbestos, in order to minimize heat loss, and is preferably provided with a suitable expansion joint 19 adjacent its upper end, as depicted in FIG. 7.

Referring now to FIG. 9, there may be seen another simplified pictorial representation of an alternative embodiment of means suitable for practicing the present invention, wherein the central shaft 13 may be drilled from the surface of the earth 2 to and across the formation 4 of interest, and wherein arcing drill holes 18 which begin at locations spaced from the top of the shaft 3 extend down to and along the formation 4 towards the shaft 3. These arcing drill holes 18 may be used as steam mixture injection lines, in lieu of the line 21 depicted in FIG. 7, with the central shaft 3 receiving oil from radials 6 extending therefrom into the formation 4 as hereinbefore explained.

Although the present invention has been heretofore discussed and illustrated primarily with respect to alternate steam mixture injection and oil recovery through the central shaft 3, it will be apparent that conventionally completed production wells (not depicted) can be provided at appropriate locations relative to the shafts 3 depicted in FIG. 3. In such an arrangement, the steam mixture will then be injected through the line 21 into the formation 4 on a continuous basis, since oil can be recovered through these alternative production wells as hereinbefore explained.

As hereinbefore stated, it is within the concept of the present invention to inject a steam mixture and the like into one or more radials 6 extending from a particular shaft 3, while simultaneously receiving oil from one or more other radials 6 extending from the same shaft 3. Furthermore, this may be done for more than one shaft 3 at the same time, in order to more effectively sweep the formation 4 of interest. Referring again to FIG. 2, it will be seen that if the steam mixture is injected into radials 6A while radials 6B are opened to drain oil into the sump 7, the injected steam mixture will tend to drive the oil into the collection points at the same time it heats the oil adjacent the shaft 3, and thus, the area about the shaft 3 will be more effectively swept with steam and inert gas and drained of oil. Referring now to FIG. 3, it may be seen that the rectangular pattern of the various groups of radials 6A–B will permit this technique to operate effectively with respect to larger areas of the field.

The present method of this invention contemplates avoiding the aforementioned disadvantages of the prior art by incorporating two modifications to the methods and apparatus presently disclosed and claimed in the aforementioned Turk et al patent application, U.S. Ser. No. 766,523, filed Feb. 7, 1977. In the first place, the present invention proposes to establish the steam injection rate at a magnitude which is not limited by a "critical velocity" within the particular formation of interest. More particularly, however, the present invention proposes to employ a mixture of steam and "stack gas" (inert gases), in lieu of the conventional pure steam which is normally injected into the formation as a part of conventional steam injection techniques.

As used herein, the term "inert gas" shall mean any gas which is both noncondensable in character at ambient formation temperatures and which does not interact with either the formation matrix or the oil or other earth materials contained therein. Accordingly, the term "inert gas" will include not only gases such as helium, methane, air, carbon dioxide, anhydrous ammonia, nitrogen, but also flue and stack gas and other combustion products from internal combustion engines, steady state burners, and the like.

There are basically two reasons for the use of an injection mixture of steam and inert gases. It is well known that steam at ambient pressure depends upon being maintained at a temperature greater than 212° F. in order to maintain its gaseous character, and that when the temperature drops below this level, the steam will suddenly condense into the liquid. During steam injection operations, the steam will necessarily eventually decline in temperature to a level whereupon the condensation of the steam within the formation will produce a distinct pressure drop which is inconsistent with the purposes of the operation. In fact, it may even produce a relative vacuum within the formation which will actually suck the oil away from the borehole, rather than pushing it towards the borehole. If a mixture of steam and inert gas is used, instead of pure steam used in conventional operations, then the inert gas will not be lost upon condensation of the steam, but will continue to travel through the formation to exercise a continued heating and driving effect upon the oil trapped therein.

An injection fluid which is composed entirely of inert gases avoids the disadvantageous effect of condensation within the formation since the inert gas will remain in the gaseous state. Inert gases, however, have a severely restricted specific heat in contrast with steam, and therefore will not carry nearly the same amount of heat into the formation as can be achieved with steam.

A further feature of the use of a mixture of steam and inert gas is that such a mixture will migrate and disperse through the formation to a much greater extent than will an injection of pure steam. This is due to the fact that the inert gas has a relatively higher diffusivity than is the case with steam.

And another important feature of the subject invention is that the inert gas will not only remain gaseous when the temperature of the mixture drops below the boiling point of water, but will migrate upward to the top of the formation to either create or enhance the gas cap within the formation. Accordingly, as repeated injection cycles are performed, the oil is not only reduced in viscosity, but the gas cap in the formation tends to be increased to the point where it will make a significant contribution to the driving forces within the formation.

It will be apparent that when the process disclosed in the Turk et al application is used, there is no contribution to the gas cap after the steam has condensed and the only driving force to be exerted upon the oil will be the force of gravity. If the Turk et al process is modified as proposed herein, however, not only will the forces of gravity still be present to deliver the oil to the same extent as may be expected with the Turk et al process, but it may also anticipate an addition to the driving forces as contributed by the buildup of an inert gas cap in the formation. Furthermore, since the laterals may be located at the bottom of the formation as taught by Turk et al, this gas cap should not be dissipated upon production of the oil, but should remain in place so as to continue to exercise the driving force sought for.

Although much has heretofore been said regarding the "critical velocity" of an operation, it should be noted that although this is a particular aspect of conventional vertical well steam injection operations and although it would also be true if conventional vertical well injection operations were conducted with a mixture of steam and inert gas, the same is not true if the present process is practiced with a mixture of steam and inert gas. The reason for this is that a critical velocity for this operation does not exist when you are seeking vertical penetration of the formation by the injected mixture, at least as that term is used with respect to conventional steam injection operations.

In the present operation, it will be noted that the laterals may be located substantially along the lower portion of the formation, and that it is expected that the injected mixture of steam and inert gas will merely rise through the formation rather than traveling laterally therefrom. In this event, velocity is not a particular factor, and therefore the steam and inert gas mixture may be injected at substantially any particular rate found to be desirable as a function of other operating parameters of the system. More specifically, in the present invention it is possible to inject the steam and inert gas mixture into the formation at high rates, which is not possible with conventional vertical well steam injection operations, and is not even possible in conventional vertical well operations wherein the injected fluid is a mixture of steam and inert gas.

It should be noted that, no matter what the character of the injected mixture may be, the overall volumetric sweep efficiency will be greater with the use of a technique such as described in the instant application, than it will be with respect to conventional vertical well injection procedures. The reasons for this superiority are that the use of the present technique will permit the steam and inert gas mixture to be injected at many points in the formation, as contrasted with only a few injection points as is the case with conventional vertical well steam injection techniques.

When the present technique is used, the injected fluid is expected to rise vertically through the formation, rather than to move horizontally through the formation as in the case of conventional vertical well injection techniques. Since the injected mixture of steam and inert gas is of a lower density than the oil sought to be treated, the injected mixture will naturally rise through the formation in a vertical direction. Accordingly, the use of the present technique tends to be an advantage over conventional techniques, since it intends to employ a phenomenon which is an undesirable characteristic of conventional vertical well injection techniques. In other words, the present method contemplates that which will occur naturally, i.e., that the injected mixture of steam and inert gas rise through the formation vertically whereas this is an undesirable characteristic of conventional vertical well techniques.

The ideal location of the laterals is usually adjacent the lower level of the formation. However, it may be advantageous in some circumstances to employ a plurality of radials extending from the subsurface chamber at various preselected vertical levels in some formations, as for example at the lower and mid-point vertical levels. The reason for this alternative arrangement is that it will take advantage of lithological differences occurring at different vertical elevations within the formation, and in particular to allow for the existence of lenses and other types of anomalies.

It should be noted that there is a novel feature in the proportion of inert gas to the quantity of steam being employed as the injection mixture. In particular, the mixture may appropriately be composed of approximately 100–600 cubic feet of gas to each barrel of water converted to steam at an 80% quality. In other words, the ideal mixture would be approximately 300 cubic feet of inert gas for each barrel of water converted into steam. It should be noted, of course, that the particular percentages may vary depending upon the type of inert gas employed, and the foregoing figures are those contemplated to be used when the inert gas is flue or "stack" gas.

As hereinbefore described, the techniques of the present invention are inferentially directed to recovery of relatively heavy oils. However, it should be noted that these techniques are not limited to heavy oils only, but can be used with substantial effect in recovering hydrocarbons of various weights and gravities.

In addition, it will be noted that the discussions hereinbefore set forth have inferrentially contemplated recovery of these hydrocarbons in primarily liquid form, whereas a suitable "soak" stage will effectively create a temperature in the formation wherein medium (35 API and the like) and high (45 API and the like) gravity oils will be effectively vaporized in the formation. Accordingly, it may be convenient for the purposes of the present invention to employ standard technology for handling and saving such vaporized hydrocarbons, as well as to recover the liquids sought to be saved. Furthermore, it should be noted that this vaporizing capability has particular applicability to situations wherein recovery is limited, not by reason of any defect with respect to the oil, but because of limited permeability of the formation matrix.

The foregoing discussions of the present invention have also been directed at least primarily to processes wherein recovery of oil, from the heated formation, is effectively the terminal stage of the procedure, whereas this is not necessarily always the case. It should be recognized that, since the primary driving mechanism is the formation pressure, and since formation pressures will inherently decline with recovery of the oil, it may often be desirable if not necessary to periodically reinforce the formation pressure.

It is well established that formation pressure tends to follow a predictable pattern of decline as oil is recovered from the formation. Furthermore, in conventional installations and especially when production is had through a vertical drill hole, the rate at which oil is recovered also tends to follow a predictable decline pattern which corresponds at least functionally with the decline pattern of the formation pressure. In an installation of the type herein contemplated, however, where the formation is tapped by drill holes positioned laterally within the formation, a distinct anomally has been noted with respect to the decline pattern of the rate at which oil is recovered from a formation of interest.

In particular, it has been noted that although formation pressure tends to follow a conventional decline pattern, from its initial peak level to the level at which oil production ceases, the rate at which oil is recovered tends to follow an expected decline pattern only during the upper and lower portions of the range between peak and zero, and that there is an intermediate portion of the pattern wherein the rate of production decline exhibits an anomally. More specifically, the production rate tends to decline in a predictably precipitous manner until the formation pressure decline reaches a first "intermediate" level. Thereafter, however, the rate of production decline gradually slackens and becomes increasingly less precipitous as the formation pressure further declines to a distinct second "intermediate" pressure level. This second "intermediate" pressure level will usually appear relatively substantially below the first "intermediate" level, but will nevertheless be still well above the lowest pressure level at which production can still be achieved from the formation.

Once the formation pressure declines below this second lower "intermediate" level, the rate at which production declines will again become relatively precipitous as would be expected. Accordingly, it is only during this pressure range between these two "intermediate" pressure levels, that the rate at which production declines is not as expected. However, it is this anomally in the decline pattern of the recovery rate of the installation which provides an opportunity to not only maximize recovery from the formation of interest, but also to more efficiently produce the oil with respect to operating costs.

In particular, this can be done by first injecting steam or the like into the formation, as hereinbefore explained, and by thereafter injecting a pressurizing fluid composed at least substantially of a non-condensible gas into the formation, also as hereinbefore described. Thereafter, and after the formation pressure has been permitted to stabilize at its "peak" pressure level, the formation is opened to permit recovery of oil from the lateral drill holes. However, production is continued only so long as the pressure drop approaches but does not exceed this second "intermediate" pressure level at which the anomally in the decline pattern of the production rate will manifest itself. At or about that point, the formation is again preferably shut in, and the step of injecting a pressurizing gas into the formation is repeated to restore the formation pressure to a level which is preferably above the original "peak" level, and which is at least substantially above the first higher "intermediate" level, before production is resumed.

It should be especially noted that the formation pressure declines in an expected manner throughout the entire range between the peak level and the level at which production ceases, and it is only the rate of production from the formation which manifests this anomally in its decline pattern, and then substantially only within the range between the first and second "intermediate" levels as hereinbefore explained. On the other hand, it will thus be apparent that during this range, and especially at those levels wherein the decline in formation pressure approaches but does not go below the lower second "intermediate" pressure level, the rate of decline of oil recovery is clearly less than the rate at which the formation pressure is declining. Thus, there is a clear advantage in producing the formation only during the pressure range wherein the formation pressure approaches but does not go below this second "intermediate" level.

The particular values of the so-called "peak" and "intermediate" pressure levels will, of course, depend upon circumstances and conditions which are peculiar to each installation, and therefore these levels will necessarily be required to be determined in order to best employ the procedures and technology of the present invention in each particular case. On the other hand, determining a pressure level with respect to the production rate of a formation can be performed with conventional techniques, and therefore these values can be readily determined by any operator of reasonable skill using only empirical methods, without departing from the essential concepts of the present invention.

The exact explanation for the foregoing anomally which is exhibited is not clearly understood with certainty, inasmuch as the anomally may be due in part to more than one reason. In particular, however, it will be noted that during the initial steam injection stage or cycle, much of the steam will tend to be condensed in the formation due to the high build-up in formation pressure, as well as because of heat transfer into the oil contained therein. For example, the eventual "peak" pressure may, in an ideal arrangement, be as high as approximately 500 PSIG or higher.

It should be remembered that, in this type of installation, the formation is tapped by a plurality of lateral boreholes each being many times longer than the portion of a vertical drill hole which actually traverses the formation in a conventional system, and that each of these lateral drill holes contains a length of multi-perforated tubing. Thus, when the formation is initially opened for purposes of recovering oil therefrom, there is a much higher immediate rate of fluid discharge from the formation than is the case with a conventional installation with a single vertical borehole. More particularly, this immediate or abrupt pressure drop, together with the high temperature in the formation, causes the water adjacent the laterals to "flash" into steam.

Some of this steam will, of course, tend to discharge into the laterals. However, a substantial quantity of this steam passes instead into and upward through the oil in the formation, to contribute to the gap sought to be created above the laterals. When this is achieved, the steam then contributes to driving the oil down to and into the laterals at an unexpectedly greater rate than is expected with relationship to the exhibited pressure decline rate (since there are more perforations in the several laterals than in the perforated portion of a vertical well casing.)

This abnormally high production rate does not continue unabated, as hereinbefore stated, but commences a more precipitous decline when the formation pressure reaches the second "intermediate" level. This, however, is due to several reasons.

In the first place, the aforementioned "flash" tends to produce only a localized effect in the portion of the formation defined by the laterals, and thus the pressurizing effect of this "flash" will inherently be limited in duration. In the second place, the temperature build-up which has been created in the formation is also localized, and especially with respect to the oil which has been reduced in viscosity. Accordingly, when this heated and therefore more moveable oil has been driven into the laterals, this has also removed a substantial amount of heat from the formation, and re-injection of steam will be required before production can be resumed at the more advantageous rate.

The particular levels of the aforementioned first and second "intermediate" pressure levels will, of course, not necessarily be the same for each production cycle, although it can be anticipated that such levels will continue to be apparent. Furthermore, it may be reasonably expected that the same levels will be encountered at adjacent locations in the same formation during corresponding cycles of this process.

Other alternate forms of the present invention will suggest themselves from a consideration of the apparatus and practices hereinbefore discussed. Accordingly, it should be clearly understood that the systems and techniques depicted in the accompanying drawings, and described in the foregoing explanation, are intended as exemplary embodiments of the invention, and not as limitations thereto.

What is claimed is:

1. A method of recovering oil and the like from a subsurface earth formation, comprising the steps of:

establishing a shaft hole extending from the surface of the earth to said subsurface earth formation;

drilling a plurality of boreholes substantially laterally from said shaft hole into said subsurface earth formation;

injecting a heating fluid comprising substantially steam into said boreholes during a first discrete time interval for transferring heat to said oil in said formation,

thereafter injecting a pressurizing fluid comprising substantially an inert gas into said boreholes during a second discrete interval for exerting a downward pressure on said oil in said formation, and

withdrawing oil from said boreholes in response to said downward pressure exerted in said formation during a third time interval following said first and second time intervals.

2. The method described in claim 1, wherein said boreholes are located adjacent the lower limit of said formation.

3. The method described in claim 1 or 2, further including:

sealing and maintaining said injected pressurizing fluid within said formation during an intermediate time interval between said second and third time intervals.

4. The method described in claim 3, wherein said plurality of boreholes lie within a substantially horizontal plane within said subsurface earth formation.

5. A method of recovering oil and the like from a subsurface earth formation, comprising

drilling at least one borehole substantially laterally into said earth formation,

thereafter injecting into said formation through said borehole a heating fluid composed at least substantially of steam,

thereafter injecting a pressurizing fluid through said borehole and into said formation to stabilize the pressure in said formation at a determinable peak level,

thereafter withdrawing oil from said borehole until the pressure in said formation declines below a first higher intermediate level and approaches but does not go below a second lower intermediate level, and

thereafter re-injecting said pressurizing fluid through said borehole and into said formation until the pressure therein rises above said first intermediate level.

6. The method described in claim 5, including the step of

thereafter again withdrawing oil from said borehole until the pressure in said formation again approaches but does not go below said second lower intermediate pressure level, and

thereafter again re-injecting said pressurizing fluid into said formation until said pressure therein again rises above said first intermediate level.

7. The method described in claim 6, wherein said heating fluid comprises a preselected mixture of steam and a non-condensible gas.

8. The method described in claim 6, wherein said pressurizing fluid is composed at least substantially of a non-condensible gas.

9. The method described in claim 6, wherein said heating fluid comprises a preselected mixture of steam and an organic solvent.

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Alberta OIL SANDS 008554
INFORMATION CENTRE

United States Patent [19] [11] **4,296,969**
Willman [45] **Oct. 27, 1981**

[54] THERMAL RECOVERY OF VISCOUS HYDROCARBONS USING ARRAYS OF RADIALLY SPACED HORIZONTAL WELLS

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[73] Assignee: **Exxon Production Research Company**, Houston, Tex.
[21] Appl. No.: **139,618**
[22] Filed: **Apr. 11, 1980**
[51] **Int. Cl.**^{3} **E21C 41/10**
[52] **U.S. Cl.** **299/2**; 166/50; 166/272
[58] **Field of Search** 299/2, 4; 166/272, 50

[56] **References Cited**

U.S. PATENT DOCUMENTS

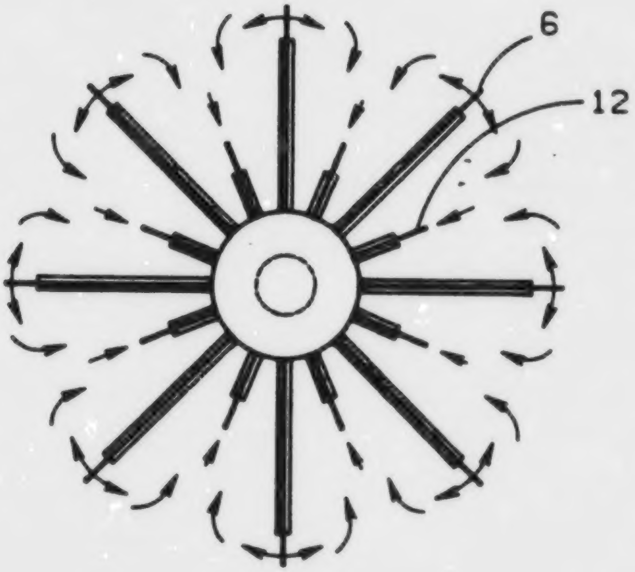
4,020,901	5/1977	Pisio et al.	166/50
4,160,481	7/1979	Turk et al.	299/2

Primary Examiner—Ernest R. Purser
Attorney, Agent, or Firm—Michael A. Nametz

[57] **ABSTRACT**

Normally immobile mineral values are recovered from a subterranean formation by penetrating the formation with an access shaft and drilling two radial arrays of substantially horizontal wells out into the formation from the shaft, one array of wells being substantially shorter than the other array. A mobilizing fluid is injected into the formation via alternate longer wells so that an outer zone of high fluid mobility is created in the formation. Then the mobilizing fluid is injected into all of the longer wells to sweep the mineral values to the shorter wells where such values are recovered. Improved sweep efficiency of the mineral values is achieved thereby.

21 Claims, 6 Drawing Figures



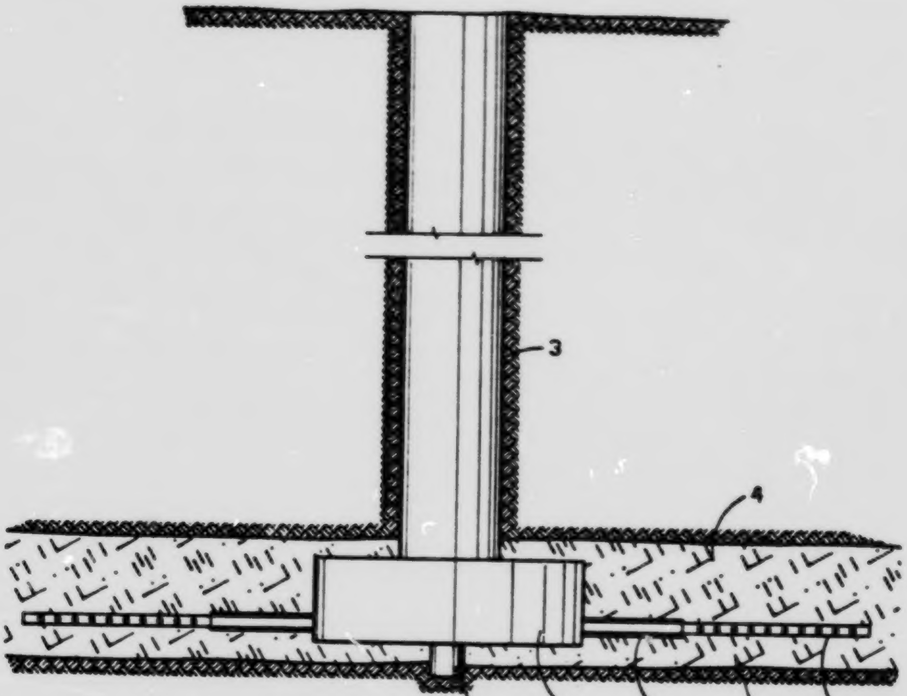


FIG. 1A

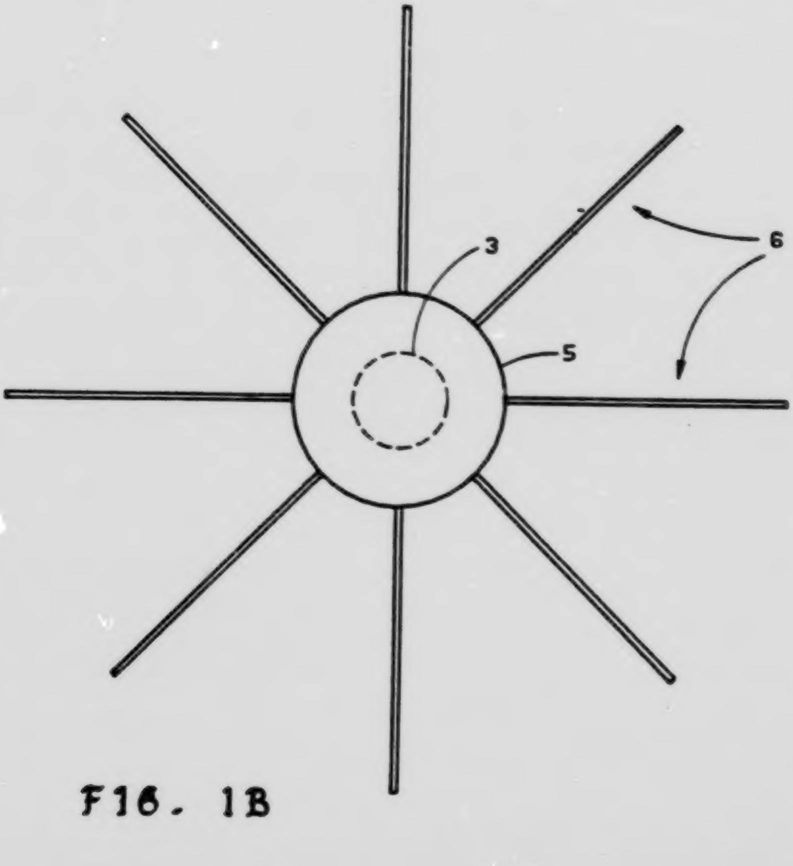


FIG. 1B

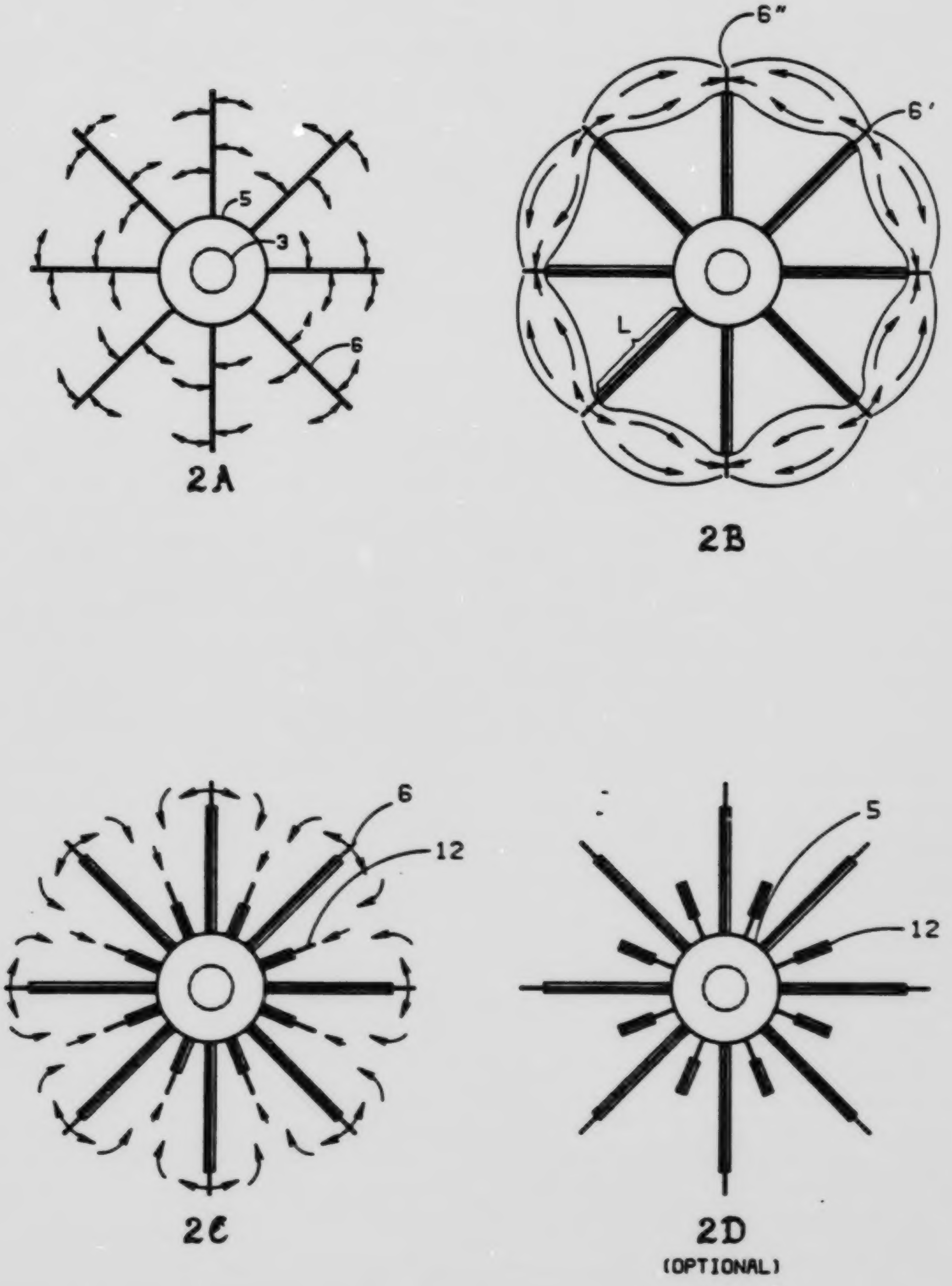

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FIG. 2

THERMAL RECOVERY OF VISCOUS HYDROCARBONS USING ARRAYS OF RADIALLY SPACED HORIZONTAL WELLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a process and apparatus for extracting mineral values from the earth. More specifically, this invention relates to a method and well system for recovering viscous hydrocarbons such as bitumen from a subterranean reservoir by injecting a heated fluid into the reservoir via an array of radially spaced horizontal wells.

2. Description of the Prior Art

In many areas of the world, there are large deposits of viscous petroleum, such as the Athabasca and Cold Lake Regions in Alberta, the Jobo Region in Venezuela and the Edna and Sisquoc Regions in California. These deposits are often referred to as "tar sand" or "heavy oil" deposits due to the high viscosity of the hydrocarbons which they contain. The distinction between tar sands and heavy oil is not settled. For both, however, normal reservoir flow rates are low, and techniques to improve flow are generally applicable to either without substantial changes including the present invention. Tar sand formations may extend for many miles and occur in varying thicknesses of up to more than 300 feet. These deposits may lie at or near the earth's surface or may be located under an overburden thousands of feet thick. However, tar sands not directly accessible from the surface consititute some of the world's largest presently known petroleum deposits. The tar sands contain a viscous hydrocarbon material, commonly referred to as bitumen, in an amount which ranges up to about 20% by weight. Bitumen is normally immobile at typical reservoir temperatures. For example, in the Cold Lake Region of Alberta, at a typical reservoir temperature of about 55° F., bitumen or heavy oil is immobile with a viscosity of about one thousand poise. However, at higher temperatures such as temperatures exceeding 200° F., the bitumen generally becomes mobile with a viscosity of less than 200 centipoise.

Since most heavy oil deposits are too deep to be mined economically, various in situ recovery processes have been proposed for separating the viscous oil from the sand in the formation itself and producing the oil through a well drilled into the deposit. Among the various methods for in situ recovery of bitumen from tar sands, processes which involve the injection of steam are generally regarded as the most economical and efficient. Steam can be utilized to heat and fluidize the immobile bitumen and, in some cases, to drive the immobilized bitumen toward production means.

The most common and proven method for recovering viscous hydrocarbons is by using steam stimulation techniques, an example being the "huff and puff" process. In this type of process, steam is injected into a formation by means of a well (the well is then sometimes shut-in to permit the steam to heat the bitumen), thereby reducing the viscosity of the crude oil. Subsequently, all formation fluids, including bitumen of reduced viscosity, water and steam, are produced from the same well using accumulated reservoir pressure as the driving force for production. Initially, sufficient pressure may be available in the vicinity of the wellbore to lift fluids to the surface; as the pressure falls, artificial lifting methods are normally employed. Production is terminated when the rate of oil production declines to an uneconomic rate. The cycle is then repeated until overall cycle economics are no longer attractive.

During the early cycles of steam injection and fluid production, oil production rates may be quite high since the oil nearest to the well is being produced. However, during subsequent steam cycles as the oil nearest the well is depleted, steam must move farther into the formation to contact the oil and as a result increased heat losses make the steam less effective as an oil recovery agent. The process looses efficiency with each cycle and eventually oil production becomes uneconomical.

Another general method for recovering viscous hydrocarbons is by using "thermal drive" processes. Such processes employ at least two wells, an injection well and a production well, spaced apart from each other by some distance and extending into the heavy oil formation. In operation, a heated fluid, usually steam or hot water, or a heat-generating fluid such as air, is injected through the injection well into the formation where it heats and drives fluids towards the production well. The dominant mechanisms for oil displacement are viscosity reduction of oil (as with steam stimulation), swelling and perhaps steam distillation, depending on the character of the oil. The principal advantage of using a thermal drive process is that higher overall recoveries can usually be obtained than with steam stimulation processes. For example, it has been the general experience in California that only relatively low recoveries are obtained overall by steam stimulation; on the other hand, while the recovery is higher with steam floods, more heat is used per barrel of oil produced.

One basic problem with thermal drive is that while the region of the reservoir which has been swept by the heated fluid or heat-generating fluid contains low residual oil saturations, generally less than half of the reservoir is swept before the flowing heated or heat-generating fluid breaks through at the production well. Once this occurs, fluid bypass tends to make further operations uneconomical. A great deal of work in the industry has been devoted to improving the fraction of the reservoir volume which can be swept by the thermal process before the heated or heat-generating fluid breaks through at the production well causing oil production to become uneconomic, i.e., improved sweep efficiencies are needed.

Many of the more promising approaches currently being developed utilize combinations of horizontal wells in order to improve oil recoveries. Such horizontal wells may also be combined with access shafts or very large-diameter boreholes capable of accommodating the passage of men and equipment.

One such process is described in U.S. Pat. No. 4,020,901 which issued on May 3, 1977 to Peter Pisio and Charles F. Kirkvolt (Chevron Research Company). This patent discloses a special arrangement of equipment for recovering heavy oil from very thick tar sand formations. The invention involves the use of heating conduits extending horizontally from a vertical shaft into the tar sand formation. Steam is flowed through the horizontal conduits to indirectly heat the adjacent formation and create a flowpath surrounding the conduits for production of fluids. In order to promote flow of heated petroleum to the flowpath, steam is injected directly into the formation via separate injection conduits. The patent discloses the use of a set of vertical injection conduits for delivering steam to the formation;

alternatively, a set of slanted wells may be used to deliver the steam to the formation. In essence, the approach taken is to sweep the heated petroleum into a laterally extending flowpath and outwardly along the flowpath. The heated petroleum is then recovered near the end of the horizontal conduit and floats into the shaft. Presumably, over time, the steam will sweep more and more petroleum to the end of the horizontal conduit thereby creating an expanding steam saturated region.

One problem with the method of U.S. Pat. No. 4,020,901 is that while the creation of a flowpath is highly desirable, the approach here will be inherently extremely slow since heat is delivered to the formation for this purpose only indirectly. Conductive heating by indirect heating of the formation adjacent the horizontal conduit will be slow. Also, the method does not utilize many of the advantages of steam stimulation, such as removal of near-wellbore damage caused by fine solids, and asphaltic paraffinic deposits. In addition, a hot path between the injection location and production location is needed to effect fluid communication; however, this hot path of very high mobility tends to cause hot injected fluid to bypass the cold, viscous oil which must be heated.

Another patent utilizing a mine shaft or other large-diameter access shaft is U.S. Pat. No. 4,160,481 which issued on July 10, 1979 to L. J. Turk and R. O. Kehle (assignee: the HOP Corporation). Some popular accounts of this method have referred to it as the "hot-plate" process. This is because steam is injected into the formation via horizontal wells which extend from a central access shaft like spokes on a wheel. The steam penetrates into the formation upwardly due to gravity and heat is transferred to the viscous oil. Once heated, the oil begins to flow. Oil and water are produced back through the horizontal wells and pumped through the vertical access shaft for treatment. The patent also discloses that oil may be more effectively swept from the formation by simultaneously injecting steam via one or more of the horizontal wells and producing oil via one or more other horizontal wells. However, the technique is primarily a steam stimulation or steam soak technique.

While U.S. Pat. No. 4,160,481 represents an advancement in systematically heating a formation and recovering normally immobile heavy oil in an efficient manner, problems still exist in the sweep efficiency of the process. It is believed that substantial quantities of oil will remain between the radially extending horizontal wells. Therefore, there is a continuing need for an improved thermal process for the effective recovery of viscous hydrocarbons from subterranean formations such as tar sand deposits, especially a process having improved sweep efficiency.

SUMMARY OF THE INVENTION

In accordance with the present invention, an in-situ process and well geometry are provided for recovering normally immobile mineral values from a subterranean formation. An access shaft is formed in the formation and a first array of radially-spaced horizontal wells is drilled from the shaft into the formation. The first array of wells is completed so that upon the injection, via alternate wells, of a mobilizing fluid capable of causing the mineral values to flow, an outer zone of high fluid mobility is formed between the ends of the first array of wells. Then, a second array of horizontal wells is drilled, radially spaced between the first array and being substantially shorter than the first array. The mobilizing fluid is then injected into the formation via said first array of wells to mobilize and drive mineral values to the second array of wells, where such values can be recovered. By creating the outer ring of high fluid mobility and using the short horizontal wells, vastly improved sweep efficiencies are achieved.

The preferred embodiment is an improved in-situ thermal method and well geometry for recovering heavy oil or bitumen. The invention is a significant improvement over the process described in U.S. Pat. No. 4,160,481. The preferred embodiment comprises the following steps: (1) forming a large diameter access shaft in a subterranean bitumenous formation; (2) drilling a first set of radially-spaced, substantially horizontal wells out from the access shaft; (3) completing each horizontal well over most of its length such that fluid communication exists with the formation; (4) injecting a heated or heat-generating fluid into the first set of wells and into the formation, and allowing the formation to soak; (5) producing oil from te first set of horizontal wells until production is no longer efficient; (6) repeating the fluid injection, soak and production cycle until oil production is no longer efficient; (7) cementing a liner in or otherwise plugging each horizontal well over a majority of its length to prevent fluid communication with the formation over the plugged portion, while leaving an end portion of each well in fluid communication with the formation; (8) injecting heated or heat-generating fluid into alternate wells of the first set of wells to displace oil to the remaining horizontal wells to create a path of thermal communication between the ends of the first set of wells (a heated annular zone of high fluid mobility); (9) drilling a second set of horizontal wells which are radially spaced between the first set and which are substantially shorter than the first set of wells; (10) injecting the heated or heat-generating fluid into the first set of wells to displace and force hydrocarbons to the second set of short horizontal wells, and producing oil from the second set of wells. Vastly improved sweep efficiency and oil recoveries can be achieved using this invention.

The "soak" period mentioned in steps (4) and (6) may be as short as the time it takes to turn the wells around following injection of heated or heat-generating fluid (i.e. without shutting in), or the wells may be physically shut-in depending on the type of oil and reservoir characteristics. In addition, it will be preferred for very viscous oils (e.g., Cold Lake, Alberta) to inject steam during the stimulation steps (4) and (6) at above formation fracture pressures. Then during the thermal drive stage steps (8) and (10), steam will preferably be injected at below fracture pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1(*a*) and 1(*b*) taken together schematically illustrate a well array for practicing the method of U.S. Pat. No. 4,160,481.

FIGS. 2(*a*) through 2(*d*) taken together schematically illustrate the method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a thermal recovery process utilizing a special well geometry to provide significantly improved sweep efficiencies over the well geometry and process of U.S. Pat. No. 4,160,481. The invention is preferably applied in recovering normally immobile carbonaceous material from a subterranean formation by heating it with a heated or heat-generating fluid, although other applications where improved sweep efficiency is a requirement will be apparent to those skilled in the art. Such applications would include the leaching of uranium or other minerals in situ. The preferred method involves the steam stimulation of a reservoir utilizing a set of radially spaced long horizontal wells, completing this set of wells so that subsequent steam flooding can be performed to create an outer annular thermal communication zone surrounding the radially-spaced long horizontal wells, drilling another set of short horizontal wells in between the initially drilled wells, and injecting steam into the formation so that oil is swept to the short wells. Preferably, both sets of horizontal wells are completed so that the reservoir volume adjacent to the accesss shaft remains cool. Optionally, the short wells may be ultimately recompleted so as to sweep oil from the reservoir region immediately adjacent to the access shaft. By practicing this invention, substantial additional quantities of oil are swept from the reservoir.

The following description will disclose an especially preferred embodiment, involving the use of steam to heat and mobilize viscous crude. However, it should be understood that the method and geometry of the present invention should not be so limited and includes the use of other heated fluids (eg. hot water, solvent vapors, etc.) or heat-generating fluids (eg. air) which can be employed to reduce the viscosity of the heavy oil. It will be apparent to those skilled in the art which fluids will be most appropriate; this selection will depend in particular upon the reservoir characteristics, crude oil characteristics, availability of the particular fluid, and so forth. It can be noted with respect to the use of a heat-generating fluid, however, that the complete combustion of oil in the area covered by the horizontal wells is not necessary. Rather, only such amounts of the heat-generating fluid as are necessary to cause the viscous crude oil to flow will usually be injected.

As mentioned, this invention is a significant improvement over the method of U.S. Pat. No. 4,160,481. The method of this patent may be better understood by referring to FIGS. 1(*a*) and 1(*b*). A substantially large diameter vertical access shaft 3 penetrates subterranean heavy oil formation 4. The access shaft 3 is provided with a larger work chamber 5 at its lower end and also a sump hole 7 beneath the chamber 5. The access shaft 3 and work chamber 5 are sized and provided with appropriate equipment so that workmen are able to descend therein to perform necessary tasks. A plurality of horizontal wells 6 are then drilled into the formation 4. These wells are radially spaced from each other, as particularly illustrated schematically by FIG. 1(*b*). A relatively short portion of each well 6 will be provided with casing 8 while the remaining portion of each well 6 will be lined with a perforated drain pipe or screened liner 9. Typical lengths of the wells 6 will range from approximately 500 to 2000 feet long. Steam is injected into the formation via the wells 6 and allowed to heat the oil. Heated fluids, including crude oil, are recovered via the wells 6. This steam stimulation cycle is repeated until oil production declines to uneconomic levels.

According to the method of U.S. Pat. No. 4,160,481, the radial wells may be used in a thermal drive or steam flooding mode, without modifying the wells or manner of injection in any manner. Unfortunately, while improved oil recoveries are possible, sweep efficiencies

will still not be satisfactory. For example, it is predicted that only from about 10% to about 50% of the potential oil recovery will be achieved in the region containing the radial wells 6 due to poor sweep. Much of the remaining oil lies in-between the radial wells 6.

The present invention involves a unique combination of proper completion techniques, improved flooding with a heated or heat-generating fluid and the drilling of additional short wells in order to significantly improve sweep and recovery efficiency. In addition, the method provides for safe operating conditions for the workmen located in the cavern 5.

FIG. 2 illustrates the sequence of steps in achieving these benefits. Again, the following description will focus on the recovery of heavy oil using steam as a heated fluid, but the invention is not limited to the use of steam (or heavy oil for that matter). The method of U.S. Pat. No. 4,160,481 is initially applied and is represented by FIG. 2(*a*). The double arrows indicate that steam is initially injected and mobilized fluids produced through all radial wells 6; that is, a steam stimulation process is applied. Wells 6 are conventionally completed, being in fluid communication with the formation over most of their length. For example, a liner slotted over most of its length may be installed in each well using well-known techniques.

It should be noted that, for heavy oil or tar sand formations, it is especially preferred to inject steam at above formation fracture pressures during the stimulation process. For example, it has been discovered that in certain formations, unless steam is injected at above fracture pressure, the stimulation process is too slow to be considered economic at current world oil prices.

After a number of steam stimulation cycles, frequently 5 to 10, oil production per barrel of steam will decline and the oil/steam ratio for the last cycle will become relatively unattractive economically. To obtain the remaining recoverable oil, which may be as high as 50 to 90 percent of that originally present in the region of the deposit containing the horizontal wells 6, a steam flooding displacement must be performed. However, because of steam bypass it will not be possible to simply utilize the well configuration of FIGS. 1(*a*) and (*b*) wherein the steam is introduced over substantially the entire length of each well 6. The geometry of the system shown in FIGS. 1(*a*) and (*b*) in such that steam will flow into and oil will be displaced from only a narrow path between the perforations immediately next to the end of adjacent casings 8. The bulk of the oil remaining between adjacent wells 6 following steam stimulation will therefore not be recovered by steam drive due to the steam short circuit.

In practicing this invention in heavy oil or tar sand formations, above fracture steam stimulation is continued until a minimum degree of oil mobility is created in the formation. In other words, the formation will be heated sufficiently so that a steam displacement process can be performed at a reasonable rate below fracture pressure. Then, with reference to FIG. 2(*b*) in particular, each radial well 6 is recompleted so as to prevent fluid communication with the deposit 4 over a majority of its length, and preferably over about 60 to about 95 percent of its length (i.e., 5–40% will communicate with the formation). This may involve squeezing cement into the liner or casing openings, or otherwise plugging some of the openings. The double-lined portions of each well in FIGS. 2(*a*)–2(*d*), for example length "L" of FIG. 2(*b*), represent the portion of each well which has been prevented from communicating with the formation. Alternate horizontal wells 6 are then utilized as injection wells and production wells, as represented schematically by FIG. 2(*b*). Steam at below formation fracturing pressure is then injected into the injection wells 6' to displace fluids (both oil and water), which are produced from the production wells 6''. Steam injection and fluid production are continued until thermal communication is established between alternate wells, i.e. a path of high fluid mobility is eastablished between the ends of the injection wells 6' and production wells 6''. As may be seen in FIG. 2(*b*), an outer heated zone of high oil mobility is created in the deposit 4. The creation of this high mobility zone is one critical feature of this invention. This permits later operation without substantial steam bypass and results in significantly improved sweep efficiencies.

The next step in practicing this invention is to drill a second set of nearly horizontal wells 12 between the original set. These wells must be substantially shorter than the initial set of wells, preferably as short as possible. Thus, if wells 6 were approximately 500–2000 feet long, the short wells 12 might be drilled out to a distance of from about 35 feet to about 200 feet. These short wells 12 are completed, as with wells 6, such that the portions of the short wells 12 adjacent to the cavern 5 are not permitted to fluidly communicate with the deposit 4. The length which is in fluid communication (eg. perforated section of a casing) is determined so as to provide a reasonable production rate, while the unperforated section will have a length consistent with a comfortable working environment in the cavern 5. For example, good working numbers for many formations for the unperforated length would be about 25–50 feet, with 10–150 foot perforated outer portion. Note that while reference is made to a perforated portion, this should not be construed as limiting; a screened or slotted liner may be used over this length, or other manner of creating fluid communication between a portion of the well and the formation. The length of the perforated portion will be determined by the desired production rate and will be consistent with avoiding excessive rates of sand production. That is, a long enough perforated length will be used to handle the anticipated flow rate, but no longer than necessary for this purpose. It should also be noted that the short wells 12 may be drilled and completed at the same time as wells 6, so long as they are prevented from communicating with the formation until the thermal drive step is ready to be accomplished. This may be done, for example, by casing the short wells, but not perforating the wells.

The original horizontal wells 6 are then converted to injection wells. Steam is injected through all original wells 6 at below fracture pressures and reservoir fluids are displaced toward the new short wells 12. This is schematically illustrated by FIG. 2(*c*).

With reference to FIG. 2(*d*), a final optional procedure will be preferred when significant quantities of oil remain adjacent to the cavern 5. The outer portion of each short production well 12 in communication with the deposit is plugged with suitable material, such as cement, and the portion of each well 12 which is adjacent to the cavity is recompleted so as to be in fluid communication with the deposit. Again, this may involve perforating this portion, or otherwise forming an opening in the casing or liner of wells 12. Residual steam pressure in the formation will then further displace oil into wells 12 for recovery.

A major purpose of leaving an unperforated zone in the short wells adjacent to the cavern 5 until just before abandonment is to provide an insulating volume in the formation surrounding the cavern 5 as a heat shield. The size of the desirable heat shield will depend on formation temperature, steam temperature, allowable cavity temperature, cavity cooling installed, and the time of operation. Generally from about 25 to about 100 feet will be suitable depending also of course on the total length of the short well.

Further details on drilling and completing horizontal wells may be found in G. E. Bezaire and I. A. Markiw, "Esso Resources Horizontal Hole Project at Cold Lake", Paper No. 79-3010, presented at the 30th Annual Technical Meeting of the Petroleum Society of CIM, May 8–11, 1979.

Finally, it may be noted that the precise quantities of steam (or other heated or heat-generating fluid) to be injected cannot be determined without knowing details of a particular reservoir; however, one skilled in the art can easily determine these quantities. For the preferred process utilizing steam, for example, the stimulation steps may utilize a total volume per well of from perhaps 20,000 to 400,000 bbls of steam having a 50%–100% quality at 150 to 2000 psi. When injecting steam at above fracture pressures, as is especially preferred for many heavy oil or tar sand reservoirs, the primary reservoir characteristic determining steam quantities will be the reservoir thickness. The steam drive steps may use a similar quality steam at below fracture pressures in amounts ranging from perhaps 0.5 to 1.5 pore volumes of the reservoir volume to be swept. These specific numbers are not intended to be limiting, however, but illustrative.

It should also be apparent to those skilled in the art that generally the horizontal wells will be located near the bottom of a given reservoir; however, this will of course depend on vertical permeabilities and the presence of horizontal low permeability regions, etc. Further, the expression "horizontal wells" will include wells having a slightly downward or upward slope in order to facilitate production of fluids.

While the foregoing discussion has been devoted to a description of a well geometry utilizing a 360° radial array of horizontal wells whose ends roughly define a circle, it should be apparent that the invention could be practiced with fewer wells whose ends need not define a circle. Such an arrangement might be appropriate, for example, for an access shaft located near the outer boundary of a given formation. This arrangement could consist of two long radially-spaced horizontal wells in combination with a single short horizontal well in between. A mobilizing fluid is injected into one long well to create a path of high fluid mobility between the ends thereof. Then, the mobilizing fluid is injected into both long wells to mobilize and drive mineral values located between the two long wells to the short well for recovery. Note that the two long wells and the short well will be geometrically arranged to provide a sufficient distance between the end of the short well and the high mobility path so that the mobilizing fluid can sweep a substantial portion of the mineral values located between the long wells before breaking through to the short well, i.e., to give good sweep efficiency. This distance is inherently sufficient with a radial array of wells as shown in FIG. 2. For most applications, a greater number of wells will be preferred in order to achieve the best sweep efficiency and good economics.

In consequence of practicing this invention, significantly higher displacement and oil recovery efficiencies are obtained. The cavity or cavern 5 is shielded to a maximum extent from the high injection pressures desirable during the steam flooding of the deposit 4. The method of this invention provides a significant improvement over the process of U.S. Pat. No. 4,160,481.

Various modifications and alterations in the practice of this invention and in particular in the heated or heat-generating fluid to be used should be apparent to those skilled in the art without departing from the scope and spirit of this invention. It should be understood that the invention claimed here should be unduly limited to the specific example or embodiment set forth herein.

Having described my invention in detail, what I claim is:

1. A method for recovering normally immobile mineral values from a subterranean formation, the method comprising:

(a) penetrating said formation with an access shaft;

(b) extending first and second radially-spaced substantially horizontal wells from said shaft into said formation;

(c) extending a third substantially horizontal well from said shaft into said formation, said third well being located between said first and second wells and being substantially shorter than either of said first and second wells;

(d) injecting a mobilizing fluid into said first well and recovering mobilized mineral values via said second well so that a path of high fluid mobility is created in said formation between the ends of said first and second wells;

(e) injecting said mobilizing fluid into said first and second wells to further mobilize and drive mineral values through said formation to said third well, the end of said third well being located a sufficient distance from said high mobility path to provide for good sweep efficiency of the mineral values located between said first and second wells; and

(f) recovering said mobilized mineral values via said third well.

2. The process of claim 1 wherein said mineral values are heavy oil or bitumen.

3. The process of claim 2 wherein said mobilizing fluid is a heated or heat-generating fluid.

4. The process of claim 2 wherein said mobilizing fluid is steam.

5. The process of claim 2 wherein said mobilizing fluid is an oxygen-containing gas.

6. A process for recovering normally immobile mineral values from a subterranean formation, the process which comprises the steps of:

(a) sinking an access shaft into said formation;

(b) penetrating said formation from said shaft with a first array of radially-spaced horizontal wells, the outer ends of these wells defining an annular zone around said shaft;

(c) completing said first array of wells so that the outer ends of these wells are in fluid communication with said formation;

(d) injecting a mobilizing fluid through alternate wells of said first array, until a high fluid mobility is created in said annular zone;

(e) penetrating said formation with a second array of horizontal wells, radially-spaced between said first array of wells, said second array of wells being substantially shorter than said first array of wells;

(f) injecting said mobilizing fluid into said formation via said first array of wells to drive mobilized mineral values to said second array of wells, and

(g) recovering said mobilized mineral values via said second array of wells.

7. The process of claim 6 wherein each of said first array of wells ranges from about 500 to about 2000 feet long and each of said second array of wells ranges from about 35 feet to about 200 feet long.

8. A thermal process for recovering normally immobile carbonaceous materials from a subterranean formation which comprises:

(a) penetrating said formation with a generally vertical access shaft having a work chamber at its lower end;

(b) extending a first plurality of wells laterally and radially outward from said chamber into said formation;

(c) injecting a heated or heat-generating fluid into said formation via said first plurality of wells to heat and fluidize a portion of said carbonaceous materials;

(d) producing said fluidized carbonaceous materials via said first plurality of wells;

(e) completing each of said first plurality of wells so as to be in fluid communication with said formation over only an outer portion thereof;

(f) injecting said heated or heat-generating fluid into and recovering fluidized carbon materials from alternate wells of said first plurality of wells to create an outer zone of high fluid mobility around said first plurality of wells;

(g) extending a second plurality of wells in fluid communication with said formation laterally and radially outward from said chamber into said formation, said second plurality of wells being substantially shorter than said first plurality of wells and spaced between said first plurality of wells;

(g) injecting said heated or heat-generating fluid into said high mobility zone via said first plurality of wells to sweep fluidized carbonaceous materials from said formation to said second plurality of wells; and

(i) recovering fluidized carbonaceous materials from said second plurality of wells.

9. The method of claim 8 wherein said heated or heat-generating fluid is steam.

10. The method of claim 9 wherein steam is injected in step (c) at a pressure above formation fracture pressure.

11. A method for recovering viscous hydrocarbons from a subterranean deposit penetrated by an access shaft which comprises:

(a) drilling a first plurality of substantially horizontal, radially-spaced wells from said shaft into said deposit;

(b) completing said first plurality of wells so that each well is in fluid communication with said deposit over substantially its entire length;

(c) injecting a heated or heat-generating fluid into said deposit via said first plurality of wells to heat said viscous hydrocarbons, and thereafter producing via said first plurality of wells mobilized fluids, including heated viscous hydrocarbons, from said deposit;

(d) recompleting said first plurality of wells so that each recompleted well is in fluid communication with said deposit over less than a majority of its length;

(e) injecting said heated or heat-generating fluid into said deposit and producing heated fluids from said deposit via alternate recompleted wells so that a path of thermal communication is established between said recompleted wells;

(f) drilling a second plurality of substantially horizontal wells from said shaft into said deposit, each of said second plurality of wells being radially spaced between alternate recompleted wells and being substantially shorter than any of said recompleted wells;

(g) completing said second plurality of wells so that each is in fluid communication over an outer portion of its length; and

(h) injecting said heated or heat-generating fluid into said first plurality of wells to drive mobilized fluids in said deposit, including heated viscous hydrocarbons, to said second plurality of wells for recovery.

12. The method of claim 11 wherein said first and second pluralities of wells are completed in steps (b), (d), and (g) such that the region of said deposit which surrounds the lower portion of said access shaft from which said wells are drilled remains relatively cool.

13. The method of claim 11 wherein said heated or heat-generating fluid is steam.

14. The method of claim 11 wherein steam is injected in step (c) at a pressure above formation fracture pressure.

15. The method of claim 11 which includes performing step (f) along with performing step (a) and preventing said second plurality of wells from being in fluid communication with said deposit until step (g) is reached.

16. The method of claim 11 which further includes:

(i) recompleting said second plurality of wells such that fluid communication with said deposit is prevented where communication was previously permitted by the completion of step (g) and such that fluid communication with said deposit is permitted where previously prevented; and

(j) producing heated fluids from said deposit via said second plurality of recompleted wells.

17. The method of claim 11 wherein each of said second plurality of wells is from about 35 feet to about 200 feet long, said outer portion is from about 10 feet to about 150 feet long, and the length of said first plurality of wells ranges from about 500 to about 2000 feet.

18. The method of claim 11 wherein each of said first plurality of wells is recompleted in step (d) so as to be in fluid communication with said formation over about 5 to about 40 percent of its length.

19. A system of wells for use in the in-situ recovery of mineral values from a subterranean formation comprising:

(a) an access shaft penetrating said formation;

(b) a first array of long, radially-spaced horizontal wells extending outwardly from said shaft into said formation;

(c) means for completing said first array of wells such that each well is in fluid communication with said formation only over an outer portion thereof, whereby a zone of high fluid mobility is created between said outer portions upon injection of a mobilizing fluid into and recovery of mineral values from said formation via alternate wells of said first array;

(d) a second array of horizontal wells radially spaced uniformly between said first array of wells, said second array of wells being substantially shorter than said first array of wells;

(e) means for completing said second array of wells such that each is in fluid communication with said formation, whereby a substantial portion of the mineral values contained between said high mobility zone and said second array of wells are swept to said second array of wells upon injection of said mobilizing fluid into said formation via said first array of wells.

20. The system of claim 19 wherein each of said first array of wells ranges from about 500 to about 2000 feet long and each of said second array of wells ranged from about 35 feet to about 200 feet long.

21. The system of claim 19 wherein each of said first array of wells is in fluid communication with said formation over about 5 to about 40 percent of its length.

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Alberta OIL SANDS

INFORMATION CENTRE

United States Patent [19] [11] **4,368,781**

Anderson [45] **Jan. 18, 1983**

[54] METHOD OF RECOVERING VISCOUS PETROLEUM EMPLOYING HEATED SUBSURFACE PERFORATED CASING CONTAINING A MOVABLE DIVERTER

[75] Inventor: **Donald J. Anderson**, Newport Beach, Calif.

[73] Assignee: **Chevron Research Company**, San Francisco, Calif.

[21] Appl. No.: **198,514**

[22] Filed: **Oct. 20, 1980**

[51] **Int. Cl.**^{3} **E21B 36/00**; E21B 43/12; E21B 43/24

[52] **U.S. Cl.** **166/252**; 166/50; 166/272; 166/274; 166/306

[58] **Field of Search** 166/252, 251, 250, 272, 166/274, 303, 306, 50, 64, 77, 187

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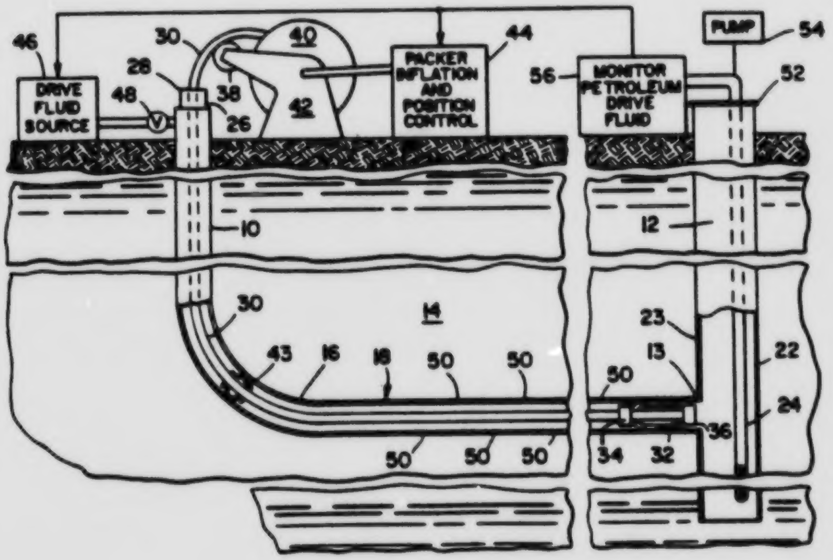
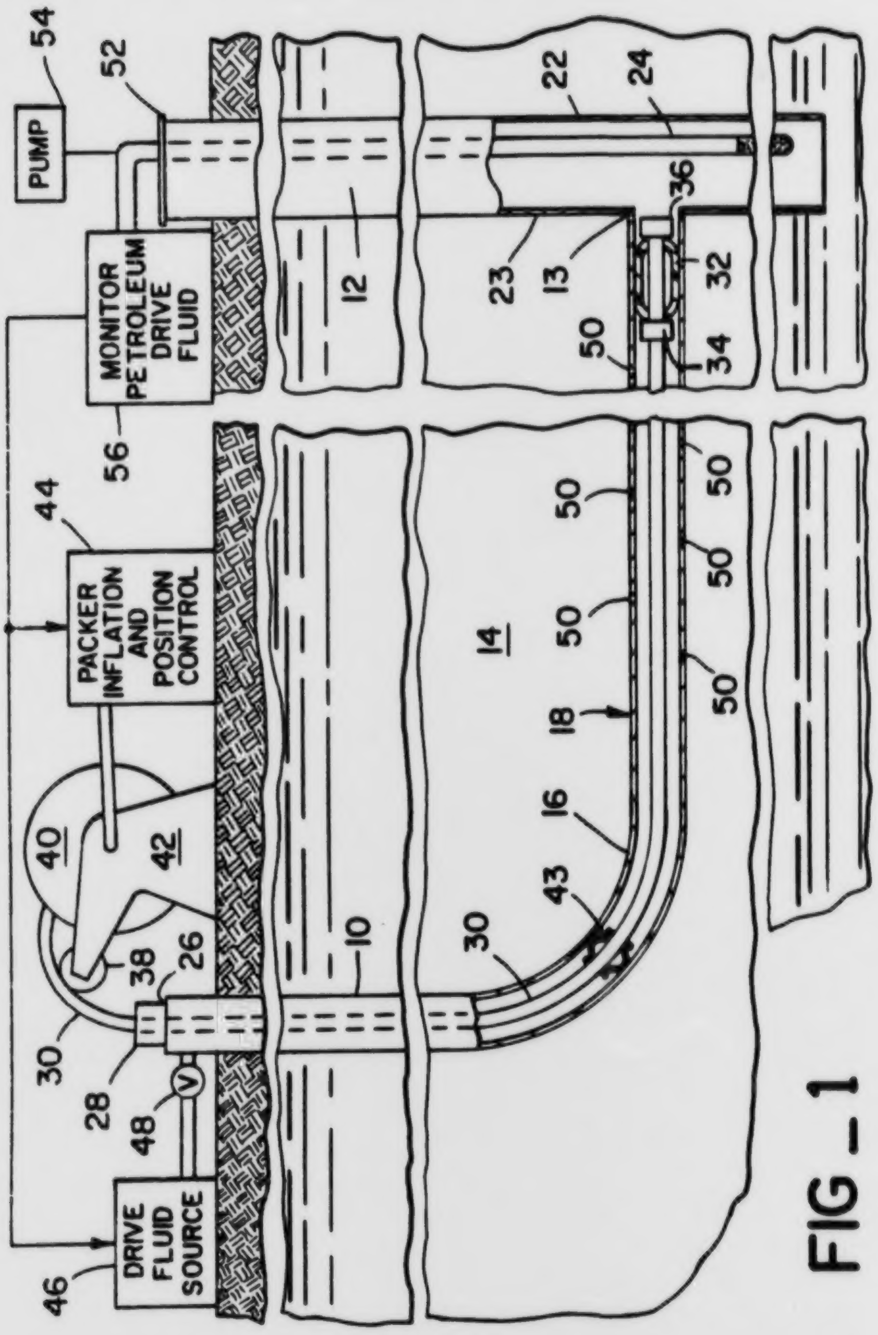
[57] ABSTRACT

A method is disclosed for recovering viscous petroleum from subsurface formation, such as tar sands, wherein a substantially horizontal, perforated casing is positioned in the formation and a movable diverter is positioned to direct a hot drive fluid out through the perforations and into the formation to move the viscous petroleum that has been heated by the drive fluid toward a production location. The production is monitored for content of drive fluid and petroleum and the position of the diverter is controlled in accordance with the monitored production to optimize the production of petroleum and to maintain the communication path within the formation between the injection location and the production location.

9 Claims, 4 Drawing Figures

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MONITOR PETROLEUM DRIVE FLUID
PACKER INFLATION AND POSITION CONTROL
V
DRIVE FLUID SOURCE

FIG_1

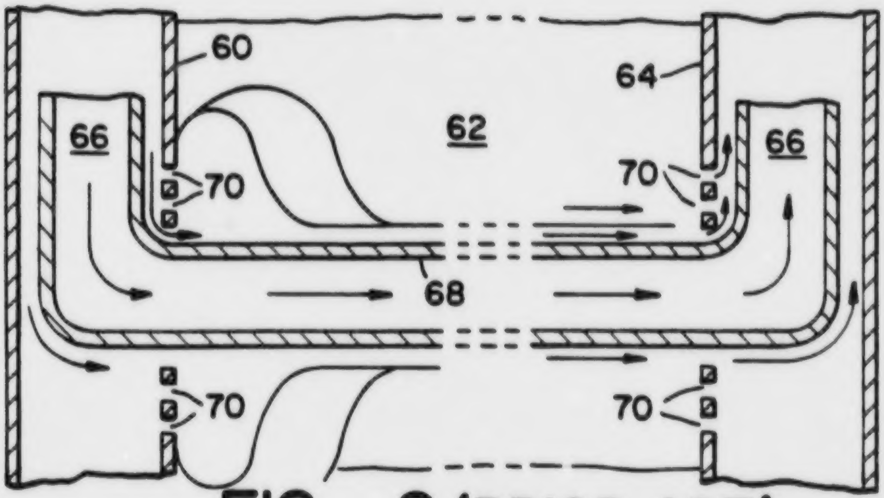
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FIG _ 2 (PRIOR ART)

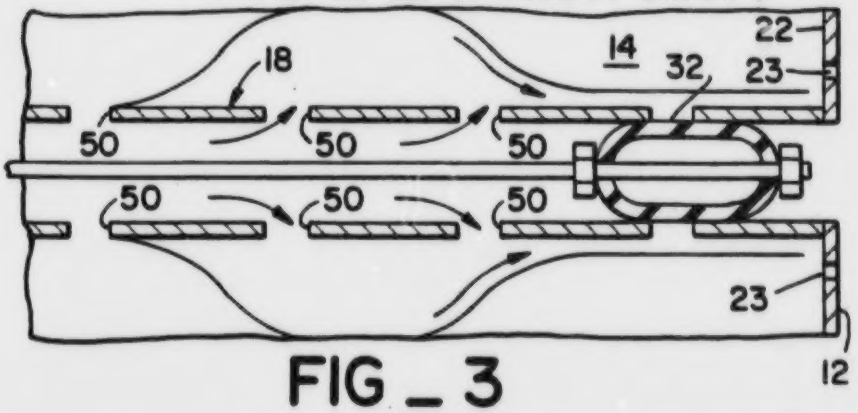
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FIG _ 3

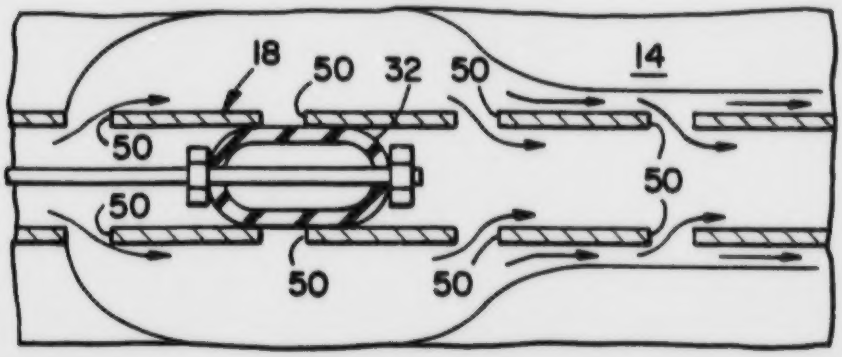
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FIG _ 4

METHOD OF RECOVERING VISCOUS PETROLEUM EMPLOYING HEATED SUBSURFACE PERFORATED CASING CONTAINING A MOVABLE DIVERTER

BACKGROUND OF THE INVENTION

This invention relates to recovering viscous petroleum from petroleum-containing formations. Throughout the world there are several major deposits of high-viscosity crude petroleum in oil sands not recoverable in their natural state through a well by ordinary production methods. In the United States, the major concentration of such deposits is in Utah and California. By far the largest deposits in the world are in the Province of Alberta, Canada. The depths of these deposits range from surface outcroppings to about 2000 feet.

To date, none of these deposits has been produced commercially by an in-situ technology. Two commercial mining operations exist, and they are in a shallow Athabasca deposit and others are proposed. There have been many in-situ well-to-well pilots, all of which used some form of thermal recovery after establishing communication between an injector well and a producer well. Normally such communication has been established by introducing a pancake fracture. The displacing or drive mechanism has been steam and combustion or steam and chemicals. Another proposal is to develop well-to-well communication by injecting steam over a period of several years into a high water saturation zone underlying the tar sand deposit at a depth of round 1800 feet. Probably the most active in-situ pilot in the oil sands uses the huff-and-puff single-well method of steam stimulation. This pilot has been producing about 5000 barrels of viscous petroleum per day for several years from about 50 wells.

The most difficult problem in any in-situ well-to-well viscous petroleum project is establishing and maintaining communication between injector and producer. In shallow deposits, fracturing to the surface has occurred in a number of pilots whereupon satisfactory drive pressure could not be maintained. In many cases, problems arise from healing of the fracture when the viscous petroleum that had been mobilized through heat cooled as it moved toward the producer. The cool petroleum is essentially immobile, since its viscosity in the Athabasca deposits, for example, is on the order of 100,000 to 1,000,000 cp at reservoir temperature.

As noted, the major problem of the economic recovery from many formations has been establishing and maintaining communication between an injection position and a recovery position in the viscous oil-containing formation. This is primarily due to the character of the formations, where effective mobility of fluids may be extremely low, and in some cases, such as the Athabasca Tar Sands, virtually nil. Thus, the Athabasca Tar Sands, for example, are strip mined where the overburden is limited. In some tar sands, hydraulical fracturing has been used to establish communication between injectors and producers. This has not met with uniform success. A particularly difficult situation develops in the intermediate overburden depths, which cannot stand fracturing pressure.

Heretofore, many processes have been utilized in attempting to recover viscous petroleum from viscous oil formations of the Athabasca Tar Sands type. The application of heat to such viscous petroleum formations by steam or underground combustion has been attempted. The use of vertical slotted liners positioned in the viscous oil formation as a conduit for hot fluids has also been suggested. However, these methods have not been overly successful because of the difficulty of establishing and maintaining communication between the injector and the producer. Clearly, if one could establish and maintain communication between injector and producer, regardless of the drive fluid or recovery technique employed, it would open up many of these viscous petroleum deposits to a number of potentially successful projects.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is directed to a method of assisting the recovery of viscous petroleum from a petroleum-containing formation and is particularly useful in those formations where communication between an injector and a producer is difficult to establish and maintain. A hole is formed through the petroleum-containing formation and a generally horizontal, hollow tubular member is inserted into the hole to provide a continuous, uninterrupted flow path through the formation. A hot fluid is flowed through the interior of the tubular member to heat viscous petroleum in the formation outside the tubular member to reduce the viscosity of at least a portion of the petroleum adjacent the outside of the tubular member to provide a potential passage for fluid flow through the formation adjacent the outside of the tubular member. The tubular member may initially be perforated in the zone where recovery of the viscous petroleum is desired or the tubular member may be subsequently perforated to provide passage ways into the formation for the hot fluids passing within the tubular member. An initial breakthrough between the formation and the producer well establishes flow of the heated viscous petroleum and the hot fluid into the producer well. A diverter, for example, a settable, inflatable packer, is placed within the tubular member to cause the hot fluid to pass out through the perforations into the formation—there acting as a drive fluid to force the heated petroleum toward the producer well. In most cases the initial placement of the packer will be close to the producing well in order to maximize the pressure gradient between drive fluid and producing well, thereby facilitating early communication and petroleum production. The ratio of produced petroleum to drive fluid is monitored in the producer well to recognize an indication of excessive pass-through of the drive fluid and, based on the observed ratio, the diverter is moved within the tubular member to optimize the petroleum economic production rate and minimize the drive fluid pass-through.

The diverter may be moved back and forth within the casing between the end near the production well and the end near the injection well to maximize both the heating of the formation and the movement of the heated viscous petroleum into the producer well. In the event of an unwanted breakthrough of the drive fluid the diverter can be moved to another location within the casing so as to maintain a desired formation heating and petroleum movement as the breakthrough heals.

In the preferred form, the hot fluid which is flowed through the tubular member is steam, and the drive fluid used to promote movement of the petroleum is also steam. Under other conditions, the hot fluid and the drive fluid may be injected intermittently. The injectivity of the drive fluid into the formation is controlled to some extent by adjusting the condition of the hot fluid flowing through the tubular member. In this manner, the sweep efficiency of the drive fluid in the formation may be improved.

In one form, the present invention deals with the recovery of viscous petroleum from a tar sand formation of an Athabasca type. An injection shaft and a recovery shaft are formed and extend from the earth's surface through the tar sand formation. A hole is formed through the tar sand formation between the injection shaft and the recovery shaft, and a solid-wall, hollow tubular member is inserted into the hole to provide a flow path from the injection shaft to the recovery shaft through the tar sand formation. A hot fluid, preferably steam, is flowed through the interior of the tubular member to heat the viscous petroleum in the tar sand formation between the injection shaft and the recovery shaft outside the tubular member thus reducing the viscosity of at least a portion of the viscous petroleum adjacent the outside of the tubular member to provide a potential passage for fluid flow through the tar sand formation adjacent the outside of the tubular member. A drive fluid is injected into the formation through perforations in the tubular member to promote flow of petroleum toward the recovery shaft and the petroleum is recovered from the recovery shaft. As noted, the preferred hot fluid is steam, although other fluids may be used. Steam also is preferred for use as a drive fluid. In some situations, other fluids such as gas, water or solvents may be useful drive fluids, either alone or in combination with steam.

OBJECT OF THE INVENTION

The principal object of the present invention is to optimize the recovery of viscous petroleum from a petroleum-containing formation wherein communication between an injector position and producer position is difficult to establish and, when once established, is difficult to maintain as a path for produced petroleum.

A further object of the present invention is a method for moving the position of injection of a drive fluid in the communication path between an injector position and a producer position in a viscous petroleum-containing formation to both optimize the production of petroleum and to maintain the communication path.

Further objects and advantages of the present invention will become apparent when the description is read in view of the accompanying drawings which are made a part of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view partially in section illustrating one form of apparatus assembled in accordance with the present invention for use in recovering viscous petroleum from an underground formation.

FIG. 2 is a sectional view representing a prior art method of recovering viscous petroleum from an underground formation.

FIG. 3 is a sectional view representing an injection profile expected with the initial position of a diverter in accordance with the method of the present invention.

FIG. 4 is a sectional view representing an injection profile expected with a subsequent position of a diverter in accordance with the method of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS OF THE INVENTION

Referring now to the drawings, and to FIG. 1 in particular, where the preferred embodiment of apparatus assembled in accordance with the invention is illustrated, FIG. 1 shows a pair of spaced-apart wells or shafts, indicated generally by the numerals 10 and 12, which penetrate the earth to a viscous petroleum or tar sand formation 14. For ease in description, well 10 will be termed an injector shaft 10 and well 12 will be termed a producer shaft 12. As here illustrated, injector shaft 10 may be a continuous well connecting with producer shaft 12 at 13. A solid-wall, hollow tubular member or casing 16 is inserted through at least the generally horizontal portion 18 of the well 10. The tubular member 16 is preferably steel and may be made up of one piece or many connecting joints as a tubing string. The outside of the tubular member 16 contacts the tar sand formation 14 in the horizontal portion 18 and eventually enters the producer shaft 12. The producer well 12 is provided with a casing 22 with perforations at 23, and enclosed therein in a producing string 24 for carrying liquids to the surface above the subsurface formation.

It is not necessary that the injector well connect with the producer well, it is only necessary that the injector be in the near vicinity of the producer well. Near vicinity can mean as far as about ten feet from the producer well. The end of the horizontal portion 18 of the producer should be close enough to accomplish the development of a communication path for heated viscous petroleum from the formation into the producer well 12 through perforations 23 in casing 22.

The generally horizontal portion 18 may vary many degrees from horizontal. It is desirable to have the casing in an alignment that will maximize the heating and driving effect of fluids passing through the casing and for that reason the casing should be generally horizontal.

The injector well 10 is provided with a well head 26 at the earth's surface including a packing gland 28 through which a hollow member 30 passes for entry into the well. Within the well 10 at the horizontal portion 18, a diverter, here shown as an inflatable packer 32, is secured between shoulders 34 and 36. At the surface, the hollow member passes over a pulley 38 and onto a reel 40 on hoist mechanism 42. Spacing means 43 are provided as needed to align the hollow member 30 within the casing 16. A packer inflation and position control 44 provides control for the positioning of the packer 32 within the tubular member 18 and provides surface control for the inflation and deflation of the packer.

The well head 26 also provides an entry path for a drive fluid into the well 10 from drive fluid source 46 through valve 48.

The horizontal portion 18 of the hollow tubular member 16 may be initially perforated at 50 or may be perforated after being positioned in the subsurface formation and after functioning as a hollow passage way between the injector well 10 and the producer well 12.

The surface end of the producer well 12 is provided with a well head at 52 through which a pump mechanism 54 may operate to lift liquids from the subsurface to the surface. The lifted liquids pass into a monitor mechanism 56 where the ratio of produced petroleum to produced drive fluid is determined. The monitor 56 includes means for controlling the packer inflation and position control 44 and the drive fluid source 46 to accomplish a desired positioning of the packer 32 within the member 18 and a desired temperature and pressure of the drive fluid. The mechanism by which these desired controls is accomplished is not essential to the present invention.

FIG. 2 illustrates a prior art form of producing viscous petroleum employing an injector well to producer well connection scheme. As here illustrated, a cased injection well 60 penetrates vertically through an earth formation of a viscous petroleum or tar sand formation 62. A cased production well 64 is positioned generally parallel to and spaced from the injection well 60. A tubular member 66 is passed down through the interior of the injection well 60, out through the casing into the formation 62, then through the formation 62 to the cased production well 64, through the casing of the production well 64 and up to the earth's surface through the interior of the production well. As shown in FIG. 2 the horizontal portion 68 of the tubular member is ideally shown as horizontal through the formation 62 and in contact with the formation at its exterior. The injection well and production well are perforated at 70 while the tubular member 66 has a solid exterior along its length.

Steam, or another hot fluid, is pumped through the tubular member 66 to heat the formation surrounding the horizontal portion 68.

Another hot fluid, or steam, is pumped through injection well 60, out through perforations 70 and into the formation 62 to function as a drive fluid for moving heated viscous petroleum through the formation 62 into the production well 64 at perforations 70 therein. Lines 72 and 74 are illustrative of isothermal profiles that might be produced as the drive fluid is pumped into the formation heated by the hot fluid passing through the horizontal portion 68 of tubular member 66.

A problem occurs with the prior art scheme when the drive fluid finds a relatively low resistance path through the formation from the injection well to the production well or out into a permeable path through the formation. Such a condition can exist when the viscous petroleum immediately adjacent to the tubular member 68 becomes mobile enough to be pushed into the production well or pushed at least laterally far enough away from the tubular member 68 to establish a finger breakthrough for the drive fluid. Once that condition has occurred, it is difficult to reestablish a continuously moving heated viscous petroleum to maintain the desired production.

The prior art scheme also has a problem of maintaining an established flow path for the drive fluid through the formation heated by the fluid in the tubular member. It is possible that the drive fluid may find a low resistance path into or through the formation in a path that does not move the heated viscous petroleum toward the production well. With only a single source for the drive fluid there is little likelihood that the loss of drive fluid into the formation can be controlled.

FIG. 3 and FIG. 4 illustrate the scheme of the present invention with apparatus positioned in a subsurface viscous petroleum or tar sand formation 14. These figures illustrate only the horizontal portion 18 of the tubular member 16 and the packer 32 in its placement and inflation position within the hollow member 30 as shown in FIG. 1. FIG. 3 illustrates the packer 32 adjacent to the casing 22 of production well 12 at perforations 23. FIG. 4 illustrates the packer positioned laterally along and adjacent to other perforations 50 in the tubular member 18.

FIG. 3 and FIG. 4 illustrate idealized paths for injected hot fluids through the perforations 50 in the tubular member 18, into the formation 14 and along the exterior of the tubular member 18 into the production well 12 through perforations 23 in the casing 22. Initially the tubular member 18 may be a conduit for hot fluids between the injection well 10 and the production well 12 to heat the viscous petroleum adjacent to the exterior of the tubular member and radially out into the formation. When the formation has been sufficiently heated to make the viscous petroleum mobile, the packer 12 may be placed in the tubular member 18 to deflect the hot fluid out into the formation to function as a pusher fluid to move the viscous crude into the production well through perforations 23 in the casing 22. The tubular member 18 may have been installed with perforations 50 or the perforations may be added after the formation has been heated. In either case, the hot fluid now passes out into the formation through perforations 50 to move the heated viscous petroleum along the formation.

As shown in FIG. 1, the produced fluids are brought to the earth's surface by use of a pump 54 or other conventional means, where the fluid is monitored for content of petroleum and pusher fluid. When the ratio of these two fluids indicates that excessive pusher fluid is being produced, indicating a probable breakthrough of the hot fluid along the exterior of the tubular member, the packer 32 is then moved from its position to another location along the tubular member 18. The move will probably be toward the injection well and away from the production well because of the initial position of the packer 32 closest to the production well 12. In the new position some of the perforations 50 will be closed to injection, others will be preferred for injection, and others that previously functioned as injector perforations may now function as producer perforations to provide a path for produced petroleum and drive fluid through the tubular member 18. While production of produced petroleum through the perforations 50 in the horizontal portion 18 may carry some sand with it from a tar sand formation, that sand production will be inadequate to cause a sanding problem in the tubular member.

By monitoring the ratio of produced petroleum and pusher fluid and controlling the position of the packer 32 within the tubular member 18 accordingly, it is possible to maximize the production of petroleum and minimize the production of pusher fluid.

Several variations in packer placement and control are contemplated. One variation is to place the packer initially closer to the injector well and allow the hot fluids to pass around the packer and along the tubular member to heat the formation. As the entire formation adjacent to the tubular member comes up to the temperature where the viscous petroleum becomes mobile, the packer may be moved toward the producer and the drive fluid is passed out through the perforations to move the viscous petroleum. Another alternative is to provide a series of packers laterally along the horizontal portion of the tubular member. The control mechanism then could control the inflation and deflation of the several packers to control heating of the formation and injection of the drive fluid.

A further alternative to this technique of diversion control is to plug, in a step-wise manner, the horizontal perforated tubular member. Several feet of the tubular member, farthest from the injection end, would be cemented off subsequent to or immediately prior to drive fluid breakthrough thus insuring that the drive fluid would pass out through the clear perforations to move the viscous crude toward the production well.

While the invention disclosed herein has been described, as operating in a tar sand petroleum-containing formation, it should be understood that the invention is not limited only to applications in tar sands. The method described would work equally as well in other formations, such as carbonate or bituminous sand deposits, for instance the Grosmont Carbonate Reef in Canada or in the bituminous sand formations in the United States, where conventional drive processes are ineffective because of virtually zero effective permeability of the formation.

While certain preferred embodiments of the invention have been specifically disclosed, it should be understood that the invention is not limited thereto as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims.

What is claimed is:

1. A method of assisting the recovery of viscous petroleum from a petroleum-containing formation comprising:

(a) forming a generally horizontal hole through a petroleum-containing formation;

(b) inserting a solid-wall, hollow tubular member into said generally horizontal hole to provide a continuous flow path through said formation;

(c) perforating said tubular member;

(d) flowing a hot fluid through the interior of said tubular member to heat viscous petroleum in said formation outside said tubular member to reduce the viscosity of at least a portion of the petroleum adjacent the outside of said tubular member to provide a potential passage for fluid flow through said formation adjacent the outside of said tubular member;

(e) positioning a movable diverter within said tubular member;

(f) injecting a drive fluid into said formation through said perforations and into said passage adjacent the outside of said tubular member to promote movement of the petroleum through said passage adjacent the outside of said tubular member to a recovery position for recovery from said formation;

(g) monitoring the production of petroleum and drive fluid at said recovery position;

(h) and positioning said diverter within said tubular member to selectively control the injection of drive fluid through said perforations to maintain said passage adjacent the outside of said tubular member and promote movement of said petroleum.

2. The method of claim 1, wherein a substantially vertical injection well and a substantially vertical production well is drilled into said petroleum-containing formation and said generally horizontal hole is formed between and connecting said injection well and said production well.

3. The method of claim 2 wherein said diverter is a settable, inflatable packer.

4. The method of claim 3 wherein said diverter is positioned with a means passing into said tubular member in said generally horizontal hole from at least one of said injection well and said production well.

5. The method of claim 4 wherein said diverter is initially positioned adjacent to said production well and moved toward said injection well through said tubular member in accordance with said monitored ratio of said hot fluid and petroleum at said recovery position.

6. The method of claim 4 wherein the effective position of said diverter within said tubular member is controlled in a series of positions away from and toward said production well to maintain hot fluid flow into said formation along said tubular member to maintain heating and movement of said heated, reduced viscosity petroleum to said recovery position, said movement of said diverter being in accordance with monitored ratio of said hot fluid and petroleum.

7. The method of claim 5 wherein said diverter is inflatable and deflatable and said inflation and deflation is controlled in accordance with the positioning of said diverter within said casing.

8. The method of claim 1 wherein said hot fluid and said drive fluid are steam and wherein the condition of at least said drive fluid steam is controlled in accordance with said monitored production of said petroleum and drive fluid at said recovery position.

9. The method of claim 1 wherein said perforations in said tubular member on one side of said diverter function as flow paths for said hot fluid and drive fluid into said formation and on the other side of said diverter as flow paths for petroleum, hot fluid and drive fluid toward said recovery position depending upon the position of said diverter within said tubular member.

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009406

Alberta OIL SANDS

INFORMATION CENTRE

United States Patent [19] [11] **4,381,124**

Verty et al. [45] **Apr. 26, 1983**

[54] METHOD OF MINING AN OIL DEPOSIT

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[21] Appl. No.: **223,896**

[22] Filed: **Jan. 9, 1981**

[51] **Int. Cl.**³ **E21C 41/10**

[52] **U.S. Cl.** **299/2**; 166/50; 166/272

[58] **Field of Search** 299/2; 166/50, 272

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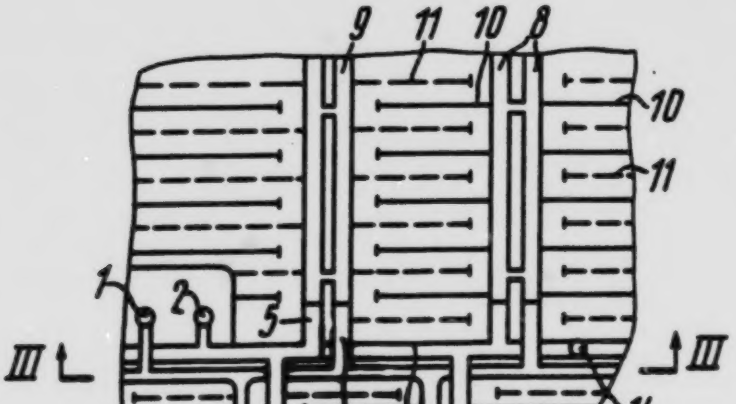
Primary Examiner—Ernest R. Purser
Attorney, Agent, or Firm—McAulay, Fields, Fisher, Goldstein & Nissen

[57] ABSTRACT

A method of mining an oil deposit, wherein a plurality of underground workings with inlet and recovery galleries are provided in an oil-bearing bed. From the inlet galleries inlet wells are drilled, and from the recovery galleries—recovery wells. A heat carrier is supplied through the recovery wells to the oil-bearing bed and oil is extracted from the recovery wells. In so doing, each inlet gallery is arranged in the bed between two recovery galleries and near the faces of the recovery wells, while the inlet and recovery wells in the oil-bearing bed portions between the inlet and recovery galleries are drilled towards each other such that they should alternate to envelop the oil-bearing bed in a uniform network of wells.

12 Claims, 4 Drawing Figures



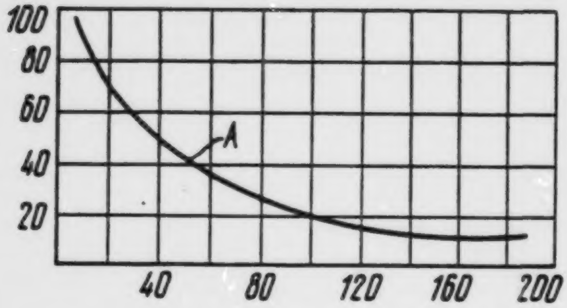


FIG. 1

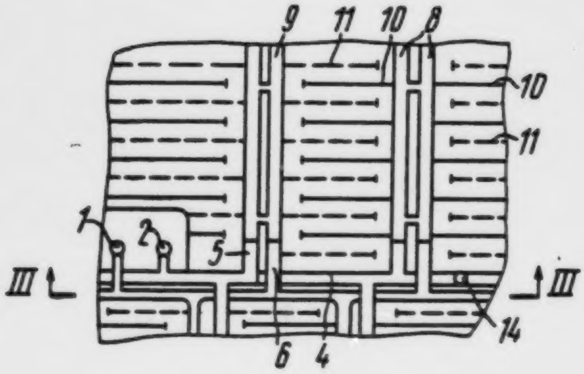

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FIG. 2

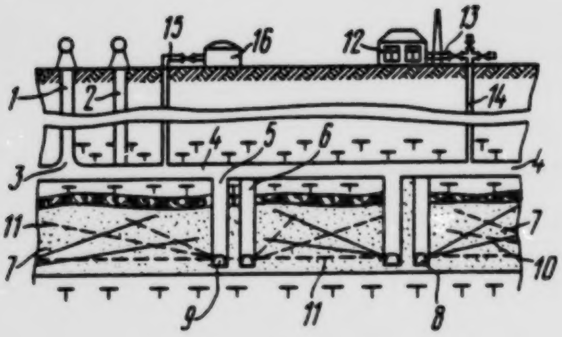
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FIG. 3

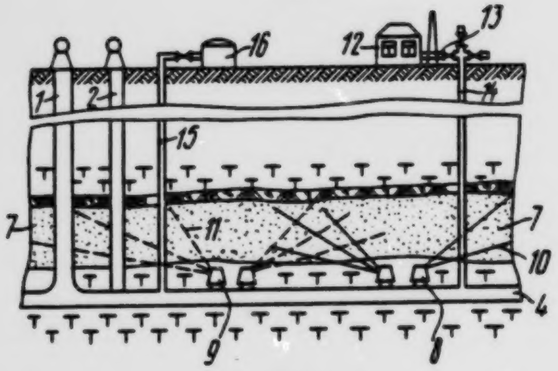
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FIG. 4

METHOD OF MINING AN OIL DEPOSIT

BACKGROUND OF THE INVENTION

The present invention relates to improving extraction of oil from oil fields and, more particularly, to a method of thermal-mining production of oil which can be used in the petroleum industry.

This invention can be used most efficiently in the extraction of oil from highly viscous oils and fluid asphalts.

The invention can also be used for developing oil deposits with depleted reservoir energy.

At present, such deposits cannot be efficiently developed by the conventional method wherein oil production is accomplished with the aid of wells drilled from the ground surface. The resulting recovery is rather low.

DESCRIPTION OF THE PRIOR ART

Known in the art for developing oil fields with highly viscous oils and fluid asphalts is a mining method of oil production without lifting oil-bearing rock to the earth's surface (cf., A. Ya. Krems et al., Shahtnaiya razrabotka neftianyh mestorozhdenii—The Mining of Oil Deposits, Gostoptehizdat Publishers, Moscow, 1955).

This prior art method comprises driving, above the roof of the oil-bearing bed, a system of underground workings including fringe drifts with drill chambers. From the drill chambers, inclined and straight wells are drilled whose depth depends on the thickness of the oil-bearing bed and the distance from its roof to the drill chambers. After drilling the wells, oil is recovered therefrom by the flowing method and then by air-lift.

When employing the flowing method, oil is lifted from the oil-bearing bed through the wells to the drill chambers by reservoir pressure; in the case of air-lift, compressed air is injected via pipes placed in the well. From the drill chambers, oil is delivered via underground workings to central underground oil collectors from which it is pumped, following primary preparation and preheating, into tanks located on the ground surface.

This method helps increase the recovery by a factor of three and above as compared with the development by means of wells drilled from the earth's surface. However, the absolute value of recovery amounts to only about 6%.

Low recovery caused a need to employ mining methods of oil production, which provide for physically affecting an oilbearing bed and the oil contained in the latter.

There is known in the art a method of thermal-mining production of oil involving the exposure of the bed to the effect of steam and heat (cf., V. N. Mishakov et al., Opyt primeneniya teplovyh metodov pri shahtnoi razrabotke mestorozhdenii vysokoviazkih neftei—On the Use of Thermal Methods upon Mining Highly Viscous Oil Deposits, in Neftianoye hozyiaistvo—Journal of Petroleum Industry, No. 10, 1974, pp. 31-35).

The above-mentioned art method provides for driving above the oil-bearing bed a plurality of underground workings including shafts, shaft workings, drifts and drill chambers.

From the drill chambers located in the drifts, straight and inclined inlet and recovery wells are drilled. A heat carrier (steam) is supplied to the oil-bearing bed via inlet

wells, which drives oil from the inlet wells to the recovery wells. From the face of the recovery wells, oil is air-lifted to the drill chambers.

Said prior art method suffers from the accumulation of sand in the recovery wells operating by the air-lift method and of the inlet wells. The recovery and inlet wells are clogged with sand from the bed.

In addition, the air-lift technique of oil production calls for equipping the wells with special pipes or devices for closing and opening the supply of air, when required, while considerable amounts of air are needed for the delivery of liquid from the wells.

This prior art method suffers from a low efficiency of the process of thermal-mining production of oil due to considerable heat losses through well walls into "barren", oil-free rock, as well as from the large amount of drilling to be done in such rock.

According to still another prior art method of oil mining (cf., U.S. Pat. No. 1,634,235), wells are drilled from underground workings located below the oil-bearing bed, and oil is extracted from shallow wells drilled from the bottom upwards. The underground workings are in this case arranged radially from the central shaft over the mining field area.

This prior art method provides for extraction of oil from the bed by gravity while the face zone of the bed is heated by way of supplying steam to the well face via pipes located in the wells.

This method suffers from non-uniform arrangement of underground workings and wells over the mine field area. Mine field portions adjoining the shaft are developed with the aid of a dense network of wells. Bed portions remote from the shaft are developed with the aid of a sparse network of wells. Such an arrangement of wells results in non-uniform mining of oil reserves.

There is also known a mining method of oil production (cf., U.S. Pat. No. 1,520,737), according to which a vertical shaft is driven through the oil-bearing bed below which a drill chamber is arranged from which inclined and ascending wells are drilled in a radial direction.

A heat carrier (steam) is supplied to the oil-bearing bed through said wells via pipes having a diameter smaller than that of the well. Heated oil flows down into the drill chamber after which it is pumped up to the ground surface.

Although this prior art method makes for a simpler process of oil recovery for an increased recovery, the bed portion under development is limited by the possibilities of drilling the inclined wells or, to be more precise, by their length. Therefore, a limited bed portion is to be provided with an individual shaft built from the earh's surface. This affects considerably the economics thereof.

Yet another mining method of developing an oil deposit, known in the art, involves the heating of oil-bearing bed by periodic injection of steam from underground workings located above a recovery gallery, via a system of inlet wells.

Without discontinuing the injection of steam, fluid such as oil and water is periodically extracted via recovery wells drilled from the recovery gallery located in the bottom portion of the oil-bearing bed. This is followed by periodic injection of hot and then cold water, while continuing the extraction of fluid via recovery wells.

This latter prior art method, regarded by the inventors as prototype of the method according to the present invention, is accomplished in the form of either a two-horizon system or a two-stage system.

Both systems suffer from a non-uniform coverage of the oil-bearing bed by the displacement process and, as a result, from low recovery.

In the case of the two-horizon system, large amounts of heat are lost to overlying rock through the walls of inlet wells, which affects the bed-heating efficiency.

In the case of the two-stage system, the bed-heating efficiency is reduced considerably because of non-uniformity of thermal effect upon the oil-bearing bed, as a result of which the peripheral zones of the area under development are heated slowly and oil fails to assume desired fluidity, this leading to lower recovery.

OBJECTS AND SUMMARY OF THE INVENTION

It is the primary object of the present invention to develop a method of mining an oil deposit for improving current oil production and the rate of oil extraction from the deposit.

It is another object of this invention to develop a method of mining an oil deposit which has increased heat efficiency.

It is still another object of the present invention to provide a method of mining an oil deposit which reduces the amount of drilling to be done in "barren", oil-free rock.

These and other related objects of the present invention are accomplished in the herein disclosed method of mining an oil deposit, which comprises:

arranging a plurality of underground workings and recovery galleries;

drilling recovery wells in rows from the recovery galleries;

arranging inlet galleries, each of them in the bed between two recovery galleries near the faces of the recovery wells;

drilling inlet wells from the inlet galleries towards the recovery wells such that the inlet and recovery wells should alternate in the oil-bearing bed portions between the inlet and recovery galleries to envelop the bed in a uniform network of wells;

force-feeding a heat carrier to the oil-bearing bed through the inlet wells for heating the bed to a temperature at which oil assumes desired fluidity in the latter and for displacing oil to the recovery wells;

extracting oil from the recovery wells to the recovery galleries; and

delivering oil from the recovery galleries via underground workings to the ground surface.

The improvement of the method according to the present invention consists in that the inlet gallery is arranged near the faces of the recovery wells, while the inlet and recovery wells in the oil-bearing bed portion between the inlet and recovery galleries are drilled towards each other such that they envelop the bed in a uniform network of wells.

An increase of current oil production and of the rate of oil extraction from the oil-bearing bed is attained as a result of heating the oil-bearing bed and oil contained in the latter and , consequently, as a result of reducing the oil viscosity, expanding oil and increasing reservoir pressure. Owing to a better coverage of the bed by the process of oil displacement by the heat carrier and a more uniform heating of the bed, an increase in recovery is attained.

An increased efficiency of the bed heating process is attained as a result of reducing heat losses through the walls of inlet wells which are drilled in the oil-bearing bed, as well as owing to additional heating of the bed upon the influx of heated oil via shaft of the recovery well through less heated portions of the bed.

The efficiency of the oil production process is attained owing to an increased recovery and higher rates of developing oil deposits, as well as owing to a manifold, sometimes complete, reduction of the amount of well drilling in "barren", oil-free rock.

The herein disclosed method provides for the maximum possible degree of bed drainage by means of horizontal, flatdipping and flat-raise wells which extend over the oil-bearing bed through dozens and hundreds of meters to interconnect its inhomogeneous zones, various channels, cracks and caverns and to increase the degree of bed completion.

The method of the invention further provides for ensuring, along with the oil displacement mode, conditions required for a display of gravity flow of oil, as well as the maximum possible simplification of the conditions of well operation.

It is expedient that in oil-bearing beds whose top portion is made up of poorly cemented loose rock or markedly fissured rock, with high-pressure water-bearing beds located below such oil-bearing beds, the inlet and recovery galleries should be located in the bottom portion of the oil-bearing bed.

With the inlet and recovery galleries located in the bottom portion of the bed, the inlet and recovery wells are fully located in the oil-bearing bed. Naturally, this helps fully eliminate heat losses to "barren" rock through well walls due to heat conductivity. All of the heat is consumed for heating the oil-bearing bed.

It is further expedient that in oil-bearing beds made up of poorly cemented and loose rock, with beds of stable and hard rock located therebelow, the inlet and recovery galleries should be located below the oil-bearing bed.

The arrangement of the recovery galleries below the oil-bearing bed makes for improved operating conditions of raise wells thanks to a reduced possibility of sand plugging. Underground air in the inlet and recovery galleries is improved owing to the location of said galleries in oil-free rock.

Since the tops of the inlet and recovery wells are in a water-bearing bed, favorable conditions exist for their sealing. Shaft portions of wells drilled in water-bearing bed present, as a rule, an insignificant fraction of the well length. In this case, heat losses to "barren" rock are negligible owing, first, to a reliable insulation of the wells in the top portion and, second, to the tendency of heat to move upwards, i.e., to the zone of oil extraction from the deposit.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be better understood upon considering the following detailed description of an exemplary embodiment thereof, reference being had to the accompanying drawings in which:

FIG. 1 shows the variation of the mean temperature of the oil-bearing bed over the length of a horizontal inlet well;

FIG. 2 is a plan view of a portion of oil-bearing bed under development with inlet and recovery wells and underground workings wherein underground workings and wells are conventionally superposed in a single horizontal plane;

FIG. 3 is a section taken along the line III—III of FIG. 2 for the case when the inlet and recovery galleries are located in the bottom portion of the oil-bearing bed; and

FIG. 4 is a section taken along the line III—III of FIG. 2 for the case when the inlet and recovery galleries are located below the oil-bearing bed.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The herein disclosed method is realized in the following manner.

A plurality of underground workings is set up, including two shafts, namely, a winding shaft 1 (FIGS. 2, 3) and a ventilating shaft 2, a mine yard 3 (FIG. 3), shaft workings which house a locomotive barn, a pumping station, storages etc. (not shown in the drawings), drifts 4, inclined workings 5 and 6 (FIGS. 2 and 3). The drifts 4 are driven above the top of an oil-bearing bed 7 (FIG. 3) and inclined horizon at an angle of from 1 to 3° from the horizontal.

The inclined workings 5 and 6 are driven from the drifts 4 (FIGS. 2 and 3) to the bottom portion of the bed or below the latter, where at least one inlet gallery 8 and recovery gallery 9 are set up.

The inlet galleries 8 are located near the faces of recovery wells (11). Both the inlet and recovery galleries (8 and 9, respectively) may be rectilinear (as shown in FIG. 2) or curvilinear, depending on the shape of the area under development.

Upon delivery of steam via horizontal or flat-raise inlet wells 10, pressure losses over the well length cause a pressure drop between the well top and face. At the same time, there is observed a temperature drop over the length of the inlet wells 10, caused by the transfer of heat to the oil-bearing bed 7 saturated with liquids.

Since low delivery pressures are employed in oil wells, low-temperature steam arrives to the tops of the inlet wells 10, while it is practically a condensate (hot water) that arrives to the well faces. Curve A in FIG. 1 indicates the mean temperature of the bed over the length of a horizontal well in one of the actual portions of the oil well.

In the bed zone adjoining the top portion of the inlet well 10 (FIGS. 2 and 3), heating is carried out by to conductivity inasmuch as this part of the well is cased-with a string. In the zone of the oil-bearing bed 7 (FIG. 3) adjoining the face portion of the inlet well 10, the bed is heated by convection heat transfer. In the face portion of the well, the pressure and temperature are rather low and have no considerable effect upon the heating of the oil-bearing bed 7.

When delivering steam at low pressures, as is often the case, the heating of the oil-bearing bed 7 is mainly accomplished by to heat conductivity from the shafts of the horizontal inlet wells 10.

As seen from the chart (curve A) showing the well length dependence of the mean temperature (FIG. 1), the highest temperature is observed in the top portion of the well. This entails an increase of the temperature of the walls of the gallery 8 (FIGS. 2 and 3) from which the wells are drilled, as well as an increased release of heat to underground air. If both inlet and recovery wells are located in one and the same gallery, this leads to aggravation of the working conditions for the personnel engaged in the recovery of oil from the recovery wells.

An increase of the amount of air used for airing causes large heat losses from the bed which, in turn, affects adversely the heating efficiency and the heat balance of the process thermally influencing the oilbearing bed 7 (FIG. 3).

In order to eliminate the afore-described disadvantages, the inlet and recovery galleries (8 and 9, respectively) are located in the bottom portion of the oil-bearing bed 7 or below the latter, the inlet galleries 8 being located near the faces of the bottom row of the recovery wells 11.

Oil assuming desired fluidity in the portions adjoining the tops of the inlet wells 10 arrives to the faces of the recovery wells 11 and then, via shafts of the recovery wells 11, to the recovery gallery 9. The heat received by oil in this zone is partly transferred to the bed upon oil movement towards the recovery gallery 9. This makes for the heating of the oilbearing bed 7 over the entire volume thereof thanks to a better coverage of the bed by the heat carrier which, in turn, helps increase the efficiency of heating the oil-bearing bed 7 and recovery factor thereof.

At the same time, temperature conditions permissible from the standpoint of labor protection and safety regulations are maintained in the recovery gallery 9 where most of the workers are stationed.

The heating front having a preset temperature gradually moves towards the recovery gallery 9 (in the direction of oil extraction via recovery wells) since the heat carrier is delivered via inlet wells 10 whose tops are near the faces of the recovery wells 11. Therefore, the extraction of oil and movement of the heating front are effected in the same direction. The time of the heating front arrival to the recovery gallery 9 can be controlled by the delivery pressure and heat carrier temperature, which, in turn, along with the better coverage of the bed by the heat carrier, offers an important technological advantage such as the setting up of proper working conditions for the personnel in the recovery gallery 9 by reducing the ambient temperature gallery.

The inlet wells 10 and recovery wells 11 in the oil-bearing bed portion between the inlet gallery 8 and recovery gallery 9 are drilled towards each other such that they envelop the bed in a uniform network of wells.

The inlet wells 10 are drilled from the inlet gallery 8 uniformly over the area under development. In particular, the inlet wells 10 may be drilled parallel to each other, as shown in FIG. 2.

The recovery wells 11 are drilled from the recovery gallery 9 (FIGS. 2, 3) also uniformly over the area under development such that the tops of the inlet wells be located near the faces of the recovery wells. In the case of a rectilinear recovery gallery 9, the recovery wells 11 are drilled parallel to each other.

The heat carrier (for example, steam) is delivered to the tops of the inlet wells 10 from a boiler unit 12 located on the ground surface, via ground pipeline 13 through a steamsupply well 14 and underground pipelines (not shown) located in the drifts 4.

The heat carrier is injected into the oil-bearing bed 7 via system of inlet wells 10. Inasmuch as the tops of the inlet wells 10 are located near the faces of the recovery wells 11, the oil first assumes the desired fluidity in the portions of the oilbearing bed 7 adjoining the zone of the tops of the inlet wells 10.

Oil is fed via the shaft of the recovery well 11 to the recovery gallery 9 and then to ditches or pipelines provided in the drifts 4.

Together with water supplied to the ditches or pipelines, oil is conveyed by gravity owing to the inclination of the workings to the horizontal on the order of 1-3° towards oil trapping units (not shown in the drawings) where it is separated from the bulk of water. Pumps can be used for conveying oil with associated water to said units via pipelines. From the oil trapping units oil is pumped over to central underground oil collectors (not shown in the drawings) from which it is fed, following primary preparation and preheat, via pipelines and through special wells 15 or through the shaft into oil storage tanks 16 located on the ground surface.

The method will remain essentially the same if the drifts 4 (FIG. 4) are provided below the oil-bearing bed 7. Moreover, such an arrangement of the drifts offers better conditions for the delivery of oil thereinto from the recovery galleries 9.

In this case, the conveyance of oil can be effected by gravity from the top of the recovery wells 11 to the oil trapping units.

The inlet and recovery galleries (8 and 9, respectively) may have the form of two twin workings (as shown in FIG. 2), as well as of a single working.

In any case, the extent of some or other galleries depends, among other things, upon the possibility of their reliable aeration in the course of driving and operation.

The oil well ventilation system should meet the requirements of labor protection and safety regulations for the service personnel.

In another embodiment of the disclosed method, when the top portion of the oil-bearing bed 7 is made up of poorly cemented, loose or markedly fissured rock, with a high-pressure water-bearing bed located below the oil-bearing bed, the inlet and recovery galleries are located in the bottom portion of the oil-bearing bed.

In this embodiment, following the setting up of the plurality of underground workings (shafts, mine yard, shaft workings, drifts in the overlying horizon, inclined workings), the method of the invention is accomplished by executing the following steps.

(1) Rectilinear recovery galleries 9 are provided in the bottom portion of the oil-bearing bed 7 at a distance of 500–700 m from each other (FIGS. 2, 3);

(2) in the design zone of the faces of the bottom row of the inlet wells 11 there are arranged rectilinear inlet galleries 8 located between the recovery galleries 9 in the bottom portion of the bed (in the top portion of the zone of transition from oil to bottom water);

(3) recovery and inlet wells (10 and 11, respectively) are drilled at a distance of 10–20 m between each other in the portion of the oil-bearing bed 7 between the inlet and recovery galleries (8 and 9, respectively). The wells are arranged in several rows (layers) over the bed thickness. In each row (layer), the inlet and recovery wells (10 and 11, respectively) are arranged alternately with each other or, depending upon geological conditions, several (2 to 5) recovery wells 11 are located between two inlet wells 10.

(4) the heat carrier (such as steam) is injected into the oil-bearing bed 7 via inlet wells 10 at a pressure of from 3 to 10 kgf/cm^2, with time intervals of from 15 to 30 days and pauses of the same duration.

Then, all of the inlet wells 10 of the element (area) under development are divided into groups, with the delivery of steam into each one of them being effected alternately, with the afore-mentioned time intervals of steam injection and shutdown of inlet wells 10;

(5) intermittent extraction of fluid (oil and water) is effected from the recovery wells 11;

(6) the cycles of heat carrier injection into the bed and oil extraction are repeated until full economically practical recovery of oil from the area under development.

In still another embodiment of the method of the invention in the case of oil-bearing beds 7 made up of poorly cemented and loose rock, with beds of stable and hard rock located therebelow, inlet and recovery wells (8 and 9, respectively) (FIG. 4) are located below the oil-bearing bed.

In this latter case, the method of the invention can be accomplished mainly through the execution of the aforedescribed steps, with due regard for the abovementioned arrangement of the inlet and recovery galleries (8 and 9, respectively).

The operating conditions of the recovery wells 11 according to this latter embodiment are improved over those described above owing to a reduced possibility of sand plugging. Underground air in the workings is likewise improved owing to the location of the latter in oil-free rock.

The use of the herein disclosed method of mining an oil deposit results in an increased current production of oil and rate of oil extraction from the oil-bearing bed 7. Conditions are provided for a more uniform and intensive heating of the oil-bearing bed, as well as for a fuller coverage of the bed by the process of oil displacement by the heat carrier, which makes for an increased recovery and, as a result, for higher efficiency in the production of highly viscous oil.

The present invention also can be used advantageously in the production of fluid asphalts.

We claim:

1. A method of oil recovery by thermal mining from an oil deposit wherein a plurality of underground workings and recovery galleries are provided, comprising:

drilling rows of recovery wells from said recovery galleries;

providing inlet galleries each in the bed between two recovery galleries near the faces of said recovery wells;

drilling inlet wells from said inlet galleries toward said recovery wells such that said inlet and recovery wells alternate in the oil-bearing portions between said inlet and said recovery galleries to form a uniform network of wells enveloping said oil-bearing bed;

delivering a heat-carrier to said bed through said inlet wells;

thereby heating said bed sufficiently to fluidize said oil therein and displace said oil towards said recovery wells; and

extracting said oil from said recovery wells to said recovery galleries.

2. The method of claim 1, wherein said oil is brought up to the surface from said recovery galleries through said workings and separated from said heat-carrier.

3. The method of claim 1 or 2, wherein said inlet and recovery galleries are drilled in the bottom portion of said oil-bearing bed.

4. The method of claim 1 or 2, wherein said inlet and recovery galleries are drilled below said oil-bearing bed.

5. The method of claim 1 or 2, wherein said inlet and recovery galleries are shaped rectilinearly.

6. The method of claim 1 or 2, wherein said inlet and recovery galleries are shaped curvilinearly.

7. The method of claim 1 or 2, wherein said inlet wells are drilled parallel to each other.

8. The method of claim 7, wherein said recovery wells are drilled parallel to each other.

9. The method of claim 7, wherein said recovery wells are drilled in the bottom portion of said bed at a distance of about 500 to 700 meters from each other.

10. The method of claim 9, wherein recovery and inlet wells are drilled at a distance of 10 to 20 meters between each other in the portion of said bed between said inlet and recovery galleries; said wells being arranged in several rows over the bed thickness.

11. The method of claim 10, wherein 2 to 5 recovery wells are arranged between two inlet wells.

12. The method of claim 11, wherein said heat carrier is introduced into said bed at a pressure of 3 to 10 kgf/cm^2 with time intervals of 15 to 30 days and pauses of similar duration.

* * * * *

0009251

Alberta OIL SANDS INFORMATION CENTRE

United States Patent [19]

Owen et al.

[11] **4,384,613**

[45] **May 24, 1983**

[54] **METHOD OF IN-SITU RETORTING OF CARBONACEOUS MATERIAL FOR RECOVERY OF ORGANIC LIQUIDS AND GASES**

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[73] Assignee: **Terra Tek, Inc.,** Salt Lake City, Utah

[21] Appl. No.: **200,320**

[22] Filed: **Oct. 24, 1980**

[51] **Int. Cl.**³ **E21B 43/243; E21C 41/10**

[52] **U.S. Cl.** **166/256;** 166/245; 166/272; 299/2

[58] **Field of Search** 166/245, 256, 259, 263, 166/266, 268, 272, 302, 50; 299/2

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Primary Examiner—Stephen J. Novosad

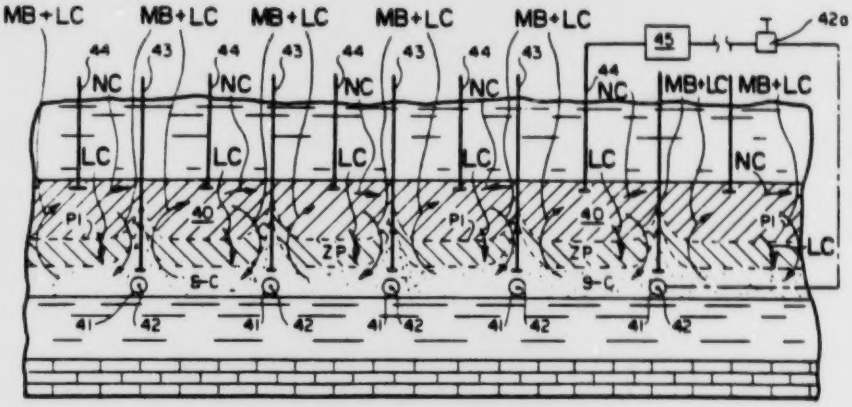
Assistant Examiner—George A. Suchfield

Attorney, Agent, or Firm—M. Reid Russell

[57] **ABSTRACT**

The method of the present invention involves a two-phase process for in-situ retorting and recovery of carbonaceous material contained within typical subterranean tar sand formations, and includes formation of conventional arrays of in-seam ducts, and positioning heating devices to heat a section of the formation over a large extent thereof. The operation of the heating devices in the first phase is controlled to provide heat into the formation without burning of the carbonaceous material therein, resulting in development of a quasi-stable zone of pyrolysis about the heating duct, to thermally crack the carbonaceous material producing various organic liquid oil fractions and derived condensible vapors and non-condensible gases. The products produced thereby are then withdrawn through a suitable array of collection wells. In the second phase of the process a residual coke layer that will have formed as a result of the pyrolysis of the carbonaceous material is burned by introducing a combustion-supporting gas, such as air or oxygen, into the hot sand-coke blanket preferrably via the line source heating ducts spontaneously igniting the coke to produce a temperature elevation in the zone of pyrolysis to both crack the proximate carbonaceous material and to burn away the coke layer from around the shut-in collection wells freeing them to continue withdrawal of the products of the cracking process. After combustion of the basal sand-coke blanket air flow to the tar sand formation will be terminated and the heater operation restored, repeating the process.

11 Claims, 7 Drawing Figures



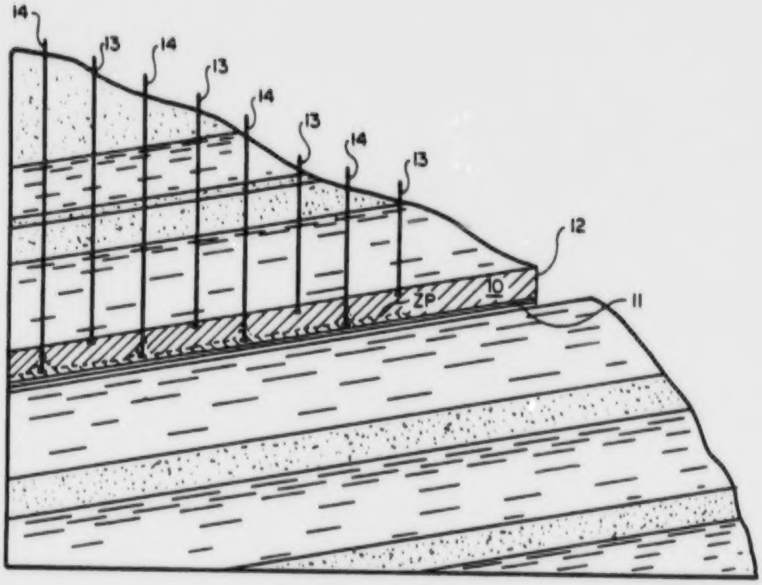

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Fig. 1

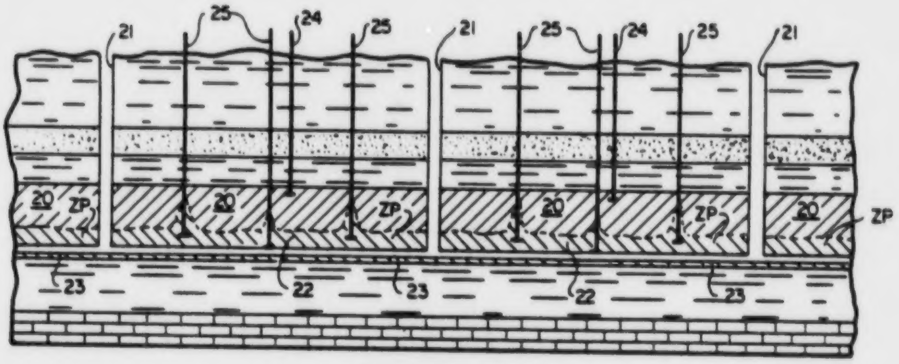
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Fig. 2

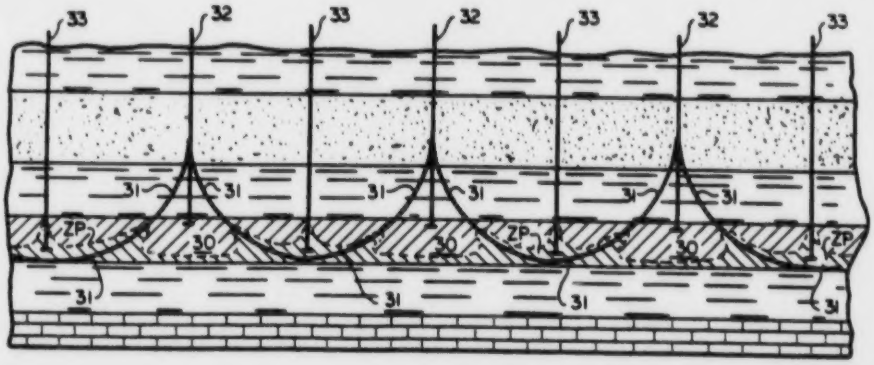
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Fig. 3

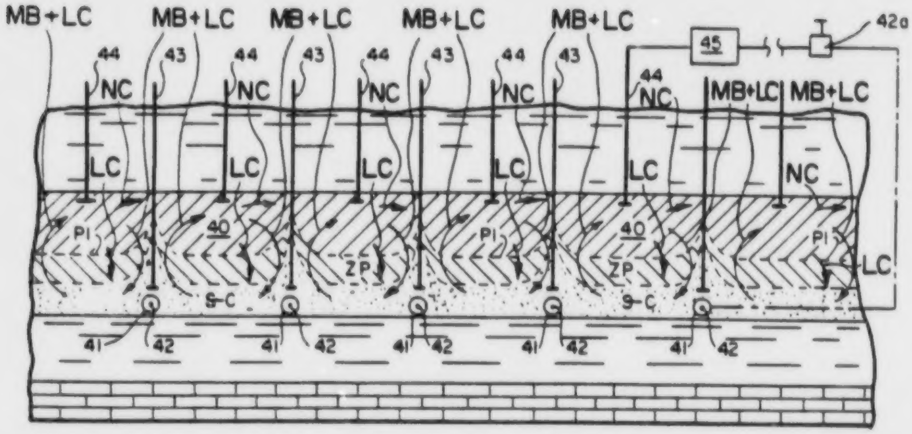
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Fig. 4

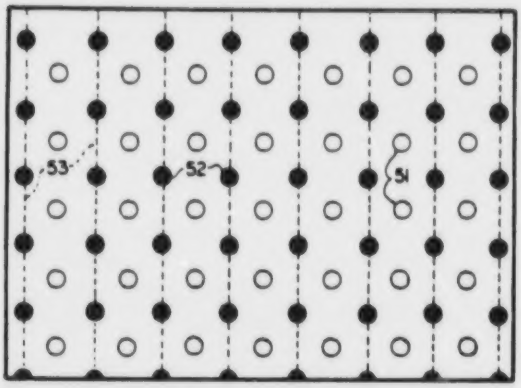

Fig. 5

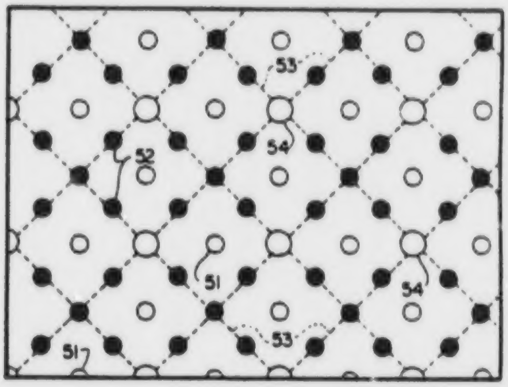
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Fig. 6

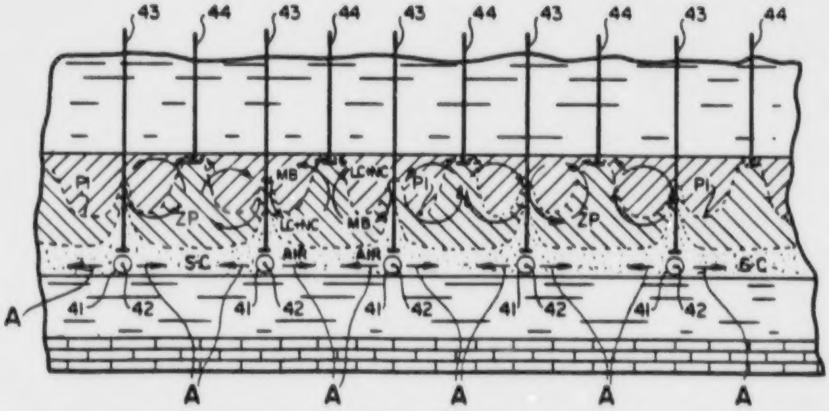
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Fig. 7

METHOD OF IN-SITU RETORTING OF CARBONACEOUS MATERIAL FOR RECOVERY OF ORGANIC LIQUIDS AND GASES

BACKGROUND OF THE INVENTION

1. Field

The method of the present invention relates to processes for in-situ retorting of tar sand formations and the simultaneous recovery of liquid and gaseous by-products. Tar sand refers to a consolidated or unconsolidated sedimentary rock in which the available pore space is filled to a varying extent with a viscous, semi-solid tar or bitumen.

2. State of the Art

The huge deposits of tar sands in the Western United States and Canada have stimulated activity by industry to devise practical and economical methods of recovery. Of the total reserves of tar sands in the United States (>28 billion barrels) and Canada, (>1300 billion barrels) less than fifteen percent (15%) are amenable to surface recovery. Therefore, the method of the present invention addresses the need for effective and cost-efficient in-situ processes for recovery of the major portions of these deposits.

Where in-situ recovery of gaseous and liquid products from tar sand formations have been heretofore described in the literature and U.S. patents, such processes have all involved penetration of the target formation by drilled vertical wellbores which are arranged in a suitable fashion and have generally included initiation of combustion of the carbonaceous material itself to provide for recovery of the retorting by-products. Examples of such former processes are shown in U.S. Pat. No. 2,584,605, issued Feb. 5, 1952, to E. S. Merriam, et al.; U.S. Pat. No. 2,718,263, issued Sept. 20, 1955, to W. O. Heilman, et al.; U.S. Pat. No. 2,874,777, issued Feb. 24, 1959, to H. J. Tadema; U.S. Pat. No. 2,994,374, issued Aug. 1, 1961, to F. W. Crawford, et al.; U.S. Pat. No. 3,087,541, issued Apr. 30, 1963, to E. R. Elzinga; U.S. Pat. No. 3,126,954, issued Mar. 31, 1964 to F. E. Campion, and all show injection of a gas, such as air or oxygen, via a vertical shaft or drillhole as an essential factor in sustaining combustion of the carbonaceous material. Another, U.S. Pat. No. 2,801,089, issued July 30, 1957, to J. W. Scott, Jr., calls for injection of a combustible gas mixture, that includes air or oxygen, via vertical boreholes or shafts or boreholes located at the bottom of the target formation, and so is also unlike the present invention.

Other earlier art that involves tar sand heating including U.S. Pat. No. 3,048,221, issued Aug. 7, 1962, to M. R. Tek, have required generation of vertical and horizontal fractures that intersect vertical production and injection wells, with combustion of carbonaceous material supported by injection of air via injection wells. This art also teaches recovery of retorted by-products by an enhanced formation permeability as provided by the artificially generated fractures. Another, U.S. Pat. No. 3,263,750, issued Aug. 2, 1966, to W. C. Hardy, teaches that retorting efficiency of tar sand formations and subsequent recovery of by-products may be significantly enhanced by injecting, via vertical wellbores, slugs of low viscosity oil with tailored boiling points such that subsequent heating of the formation, via vertical injection wells, and maintenance of combustion by injection of air, to preclude formation of oil blocks in the tar sand formation. Also, U.S. Pat. No. 2,914,309, issued Nov. 24, 1959, to G. J. W. Salomonsson, teaches uniform heating of a tar sand formation by use of moveable heaters suspended in vertical wellbores. This patent claims that the efficiency of a retorting process is enhanced by injection of air, via vertical wellbores, to sustain combustion of a portion of the carbonaceous material contained within a target formation.

All the above-cited processes for in-situ retorting of tar sand formations require that a burn front move through the formation. Therefore, they all suffer from the common deficiency of failing to insure that air, oxygen or other gases, required to drive the process by supporting combustion of the carbonaceous material contained within the formation, are uniformly distributed within the formation and are therefore unlike the process of the present invention.

The two-stage process disclosed in the present invention represents a significant departure from prior art within our knowledge and is a significant departure from that taught in the public domain technical literature pertaining to so-called mine assisted in-situ processing (MAISP) that have as an objective to thermally mobilize bitumen using horizontal subterranean tunnels as heating conduits. Such art includes the arrangement of a U.S. Pat. No. 4,196,814, issued Aug. 15, 1978, to G. B. French, and is as detailed in a technical paper presented to a 13th Canadian Rock Mechanics Symposium in Toronto, Canada, held May 28 and 29, 1980, by D. W. Develny and J. M. Raisbeck, entitled "Rock Mechanics Considerations for In-Situ Development of Oil Sands". Rather, unlike prior processes, the present invention provides for heating via stationary line sources within the formation so as to provide a convective heat transfer system that is maintained by generation of volatiles derived from the pyrolysis of mobilized bitumen adjacent to the line source heaters. The pyrolysis zone, produced by operation of stationary line source heaters, is quasi-stationary, where as in other in-situ retorting processes, a burn front, and pyrolysis zone, are propagated through the tar sand formation. Establishment of a forced convective heat transfer system leads to further reduction of the viscosity of the hot mobilized bitumen by the solvent action of convecting thermally cracked low viscosity oils and their condensible vapors and creation and continual growth, both laterally and upward, of a high permeability zone of sand-coke. Recovery of liquid and gaseous retorting by-products so produced is preferably accomplished via an array of designated vertical boreholes.

The high permeability zone of sand-coke that builds up in the thermal cracking process is then utilized as a heat source in a second stage process of the present invention where air-supported combustion thereof is accomplished by air injection via the line source heating duct. That air injection provides a significant economic incentive with respect to diminished energy requirements for continuous operation of line source heaters and is controlled to just burn the sand-coke zone whereupon the air injection is discontinued and heating at the stationary line source is resumed.

In other in-situ processes, unlike that of the present invention, the efficiency of thermal cracking of tar is relatively low due to the inability to control the flow of air or oxygen to the combustion zone and the inability to control combustion kinetics of the virgin bitumen. With the present invention, bitumen which passes into the zone of pyrolysis, as defined by the appropriate temperature-pressure relationship and specific characteristics of the bitumen, is converted to thermally cracked by-products with an efficiency of greater than ninety percent (90%).

SUMMARY OF THE INVENTION

It is, therefore, a general object of the present invention to provide a method for efficiently retorting a carbonaceous material contained within a typical tar sand formation, in place, without requiring that a significant portion of the carbonaceous material be combusted, while simultaneously recovering the liquid and gaseous by-products.

It is, therefore, an additional object of the present invention to provide for heating of the carbonaceous material without requiring burning thereof.

It is an additional object of the present invention to provide for retorting of the carbonaceous material by forming horizontal to inclined in-seam ducts within the basal section of a tar sand formation and burning a hydrocarbon fuel, or circulating hot gas or operating electric heaters therein to thermally crack the formation producing liquid and gaseous by-products therefrom.

It is an additional object of the present invention to provide, for retorting of a carbonaceous material contained within a typical tar sand formation, a two stage process where, without burning of the originally in-place carbonaceous material, heat is introduced to develop a quasi-stable zone of pyrolysis to thermally crack from the formation various organic liquid oil fractions and derived condensible vapor and non-condensible gases, creating a sand-coke layer that is then burned, further cracking hydrocarbons from the formation by a controlled introduction of air or oxygen gas therein until the coke layer is fully combusted.

It is an additional object of the present invention to provide for utilization of non-condensible gases produced in the cracking process as heating gas for burning in the carbonaceous material along with the hydrocarbon feedstock.

Retorts are formed in the tar sand formation by emplacing conventional horizontal to inclined, in-seam ducts within the basal section thereof. These ducts are subsequently fitted with heaters such that each duct represents a line source heater. The ducts may be emplaced by a variety of conventional techniques including, but not limited to, downdip drilling from benches cut along outcrops, drilling or mining of vertical large diameter shafts and subsequent mining or drilling of radially distributed, horizontal to near horizontal drifts or completion of directionally drilled holes initiated from common drill pads.

Thereafter, an array of deep vertical wellbores is interspersed above the heating ducts in patterns selected to lead to the efficient recovery of liquid and gaseous by-products of the in-situ retorting process of the present invention. Preferably, wells are completed adjacent to the line source heaters over a vertical distance corresponding to, preferably, the lower one-third (⅓) of the total tar sand formation apparent thickness to produce a product that is enriched primarily in thermally cracked oil and condensible vapors and also a lesser amount of noncondensible gases and uncracked, thermally mobilized bitumen. Also, additional vertical wells are preferably completed over the upper one-third (⅓) of the total tar sand formation apparent thickness, interspersed with the other collection wells in an optimal pattern to produce a product that is then enriched in relatively cool, non-condensible gases. Such non-condensible gases produced as by-products of the in-situ retorting, following appropriate treatment as required on the surface, are then available, by virtue of their content of combustible gases, as a source of heating gas. The liquid fraction and condensible gases produced as by-products of the in-situ retorting, following appropriate treatment, as required at the surface, are available, by virtue of their hydrocarbon content, for conventional applications which require liquid hydrocarbon feedstock, fuel or lubricants.

Unique to the present invention is the heat application to the formation via stationary, horizontal to near horizontal, or inclined in-seam line sources, that preferably are arranged parallel to the formation bedding planes such that heat transfer within the formation is accomplished by the formation of, and action of, forced convective cells driven by non-condensible gases, water vapor and thermally cracked organic liquids and condensible gases. Heat transfer to virgin bitumen is accomplished primarily by conduction as the hot gases and liquids, which constitute a portion of the convection cells, move through the tar sand formation. Passage of mobilized bitumen through a quasi-stable pyrolysis interface defined by the appropriate pressure dependent isothermal surface results in thermal cracking of the bitumen and generates a sand-coke mixture, with higher permeability to gases and liquids than possessed by the virgin tar sand formation. The sand-coke blanket continually expands laterally and upward toward the top of the tar sand formation. Hence, as the in-situ process described in this invention progresses, the heat transfer efficiency of the forced convective cells continually improves.

As a second phase of the present invention, air or oxygen is provided into a sand-coke blanket built in response to the establishment of a forced convective heat transfer system and migration of bitumen into a zone of pyrolysis distributed about the line source heaters to support heating thereof. Ignition of the coke blanket by exposing it to a stream of oxygen-containing gas, such as air, can be accomplished in order to favorably impact process economics, with the air injected via in-seam line sources. The injected air stream follows paths previously followed by volatiles formed during the initial stages of the process when the line source heaters were in use. Burning of the coke provides a subsidiary source of heat energy to continue driving the forced convective heat transfer system, and therefore complete ignition of the coke buildup is not required.

The pattern of by-product deep collection wells established over the array of line source heaters is such that breakthrough of injected air to any collection well can be immediately detected and, as a result, air flow to the heating ducts immediately adjacent to such collection well may be reduced or terminated as conditions warrant. Therefore, the air injection process to burn the sand-coke blanket can be controlled and continuously monitored to avoid air-supported combustion of virgin bitumen.

Phase-two processing is terminated by discontinuing air injection, and phase-one processing reinitiated by a resumption of operation of the line source heaters contained within the ducts and by resuming operation of by-product deep collection wells completed adjacent to the line source heating shafts. The pressure gradients imposed by operation of the deep collection wells completed adjacent to the line source heaters will lead to rapid resumption of the phase-one forced-convective heat transfer system.

The overall two-stage described process of the present invention is repeated as necessary to accomplish conversion of virgin bitumen to thermally cracked by-products with high efficiency and to simultaneously recover thermally cracked by-products with high efficiency.

THE DRAWINGS

These and other aspects of the invention will be fully understood by referring to the following description and the accompanying drawings that show:

FIG. 1 is a schematic cross-sectional view showing construction of an in-situ retort in a tar sand formation including installation of an in-seam line source heating duct parallel to the dip of the formation, from a bench cut in an outcrop, and showing an array of retort by-product collection wells and showing with broken lines, a zone of pyrolysis;

FIG. 2 is a schematic cross-sectional view showing an in-situ retort system constructed in a tar sand formation by installation of vertical shafts and radially distributed in-seam drifts therefrom;

FIG. 3 is a schematic cross-sectional view showing an in-situ retort constructed in a tar sand formation by installation of directional drilled wellbores from a central drilling pad;

FIG. 4 is a schematic cross-sectional view taken parallel to the strike of a tar sand formation, showing the distribution of retort by-product collection wells and showing, with arrows, the flow of the forced convective heat transfer system to thermally crack in Phase I of the invention the virgin bitumen;

FIG. 5 is a top plan view of a linear distribution of heating ducts shown in broken lines, and their relationship to the array of retort by-product collection wells;

FIG. 6 is a top plan view of a radial distribution of heating ducts, shown in broken lines, and their relationship to the array of retort by-product collection wells; and

FIG. 7 is a schematic cross-sectional view like that of FIG. 4, only illustrating with receding broken lines how a hot sand-coke blanket may be ignited by contact with a combustion-supporting gas in Phase II of the invention to provide heat to assist in maintaining the forced convective heat transfer system.

DETAILED DESCRIPTION

With reference to the drawings, the present invention involves a two-stage method for the in-situ retorting of tar sand and provides for a simultaneous collection of the by-product hydrocarbon liquids and gases of that retorting process.

FIGS. 1 through 3 illustrate, in schematic, the formation in a subterranean tar sand formation of conventional near horizontal or inclined, in-seam, stationary line source heating arrays. FIG. 1 illustrates construction of heating ducts by conventional horizontal drilling or mining techniques in a tar sand formation 10 when the heating ducts 11 are run downdip from benches cut 12 in accessible outcrops. FIG. 2 illustrates vertical drilled, larged bore shafts 21, hereinafter referred to as vertical shaft, that are run to the basal section 22 of a tar sand formation 20 with radially distributed horizontal or dipping drifts or ducts 23 developed from the vertical shaft 21, by means of conventional horizontal drilling or mining techniques. FIG. 3 illustrates an arrangement of radially distributed horizontal or inclined in-seam heating ducts 31 that can be bored, utilizing conventional directional drilling techniques from a single drilling pad into a tar sand formation 30.

The in-situ retorting process of the present invention is accomplished in Phase I by supplying heat to the tar sand formation by burning of a combustible material in the heating ducts 11, 23 and 31. The actual mode of formation heating can utilize any one of several conventional options including, but not limited to, the placement of gas burners, for the ignition of a combustible gas-air mixture, within the heating ducts, or emplacement of electrical heaters within the heating ducts or passage of hot gas through the heating ducts, or the like.

Illustrated also in FIGS. 1, 2 and 3, are, respectively, shallow vertical well bores 13, 24 and 32 and deep vertical well bores 14, 25 and 33. As will be explained hereinafter, the shallow well bores to recover non-condensible gases and other by-products, and the deep well bores to recover organic liquids, condensible gases and other by-products.

FIG. 4 is included to illustrate the technical aspects of the present method in relationship to the actual in-situ retorting of carbonaceous material. FIG. 4 shows, in sectional view, a tar sand formation 40 wherein are arranged heating ducts 41 containing heaters 42. Heaters 42, as described above, can consist of burners arranged to burn a combustible air-gas mixture, can be electric heaters, can be arrangements for passing hot gas, or the like, within the scope of this disclosure. Heat so supplied to the heating ducts 41 passes into the formation 40 and causes thermal cracking of virgin bitumen in the tar sand formation immediately adjacent to the heating ducts 41. The retorting process causes production of lighter weight organic liquids, condensible and non-condensible gases and water vapor.

In practicing the method of the present invention, it is the upward migration of the products of hot thermal cracking of bitumen along with water vapor that is the primary mode of heat transport. Intimate contact between virgin bitumen and hot gases and liquids plus partial mixing of hot gas and liquids with virgin bitumen will cause the bitumen to undergo a viscosity decrease, that results in mobilization of virgin bitumen at the face of a pyrolysis zone, as defined below, and as illustrated in broken lines in FIGS. 1 through 4 and identified as "ZP". The net direction of movement of the bitumen is downward under the influence of gravity as shown by arrows labeled MB+LC in FIG. 4. The "MB" represents mobilized bitumen and the "LC" represents liquids and condensible gases. The liquid and condensible hydrocarbons, derived from the thermal cracking of bitumen eventually cook, become more dense, and begin to settle under the influence of gravity, shown in FIG. 4 as arrow LC. Water vapor also condenses and beings to settle under the influence of gravity. The non-condensible gases derived from the thermal cracking of bitumen, shown in FIG. 4 as arrow NC, the "NC" representing non-condensible gases, collect along the upper portions of the tar sand formation and begin to form a gas cap. The forced convective heat transfer system is completed as mobilized bitumen and cooled water, and organic liquids flow downward and pass through the pyrolysis interface, PI, into the zone of pyrolysis where rapid reheating occurs, as illustrated by the arrows labeled MB+LC and LC in FIG. 4. In operation, withdrawal of the mobilized bitumen liquids and condensible gases is through deep well bores 43, with non-condensible gases withdrawn through shallow well bores 44, as shown in FIG. 4. Also, the shallow well bores 44 are preferably connected, as appropriate, after cleaning, and filtering as illustrated by a box 45, to supply make-up gas for burning in heaters 42, which connection is illustrated as a valve 42*a*.

The pyrolysis interface shown in broken lines as ZP in FIG. 4, is defined by the minimum isothermal surface required to produce a significant degree of thermal cracking of virgin bitumen. For typical tar sands, temperatures between 400 to 650 degrees centigrade would be required to insure nearly complete conversion of bitumen to coke plus distilled products. The actual temperature requirement in any particular case required to insure high conversion efficiency is a function of the depth-pressure environment, water content, heating times, and the chemical properties of the specific bitumen. As temperatures increase uniformly along any path as the pyrolysis interface is passed and the radial distance to the heating shafts diminishes, it is not a requirement that the entire thickness of the tar sand formation be elevated to the pyrolysis temperature. Rather, all that is required is that a zone of pyrolysis be established and that mobilized bitumen migrates from distal portions of the tar sand formation into the zone of pyrolysis.

To recover the products of the above-described retorting process of Phase I, an array of vertical wellbores is completed above the heating ducts, as shown in FIGS. 1 through 4, for collection, as described, of the by-products of the in-situ retorting process. Such collection well array, as illustrated in FIGS. 5 and 6, consist, as described, of two groups of wells distinguished by the depth interval over which they are completed. As detailed hereinabove, one set of wells is completed within the upper one-third (⅓) of the apparent thickness of the tar sand formation, identified as shallow wells 51 in FIGS. 5 and 6. These shallow wells are used, during Phase I of the process, to collect a product primarily enriched in non-condensible gases and can, as shown in FIG. 4, be connected appropriately to supply make-up gas for combustion in heaters 42. A further function of these wells is to control gas pressures in the upper portions of the tar sand formation so as to preclude environmentally damaging releases of non-condensible gases. During Phase II of the process, as will be described later herein, these wells collect by-products that are enriched in bitumen-pyrolysis distillates.

A second set of by-product collection wells, identified as deep wells 52 in FIGS. 5 and 6, are completed within the lower one-third (⅓) of the apparent thickness of the tar sand formation. These wells collect a retort by-product that is primarily enriched in bitumen distillates, during Phase I of the process. These wells, as will be described, are shut-in during Phase II of the process. Preferably, deep wells 52 are located, as shown also in FIGS. 5 and 6, adjacent to the line source heaters in ducts 53, identified by broken lines, which ducts can be formed as shown in FIG. 5 by directional drilling techniques as illustrated in FIG. 3 or boring into a bench cut as illustrated in FIG. 1. In FIG. 6, vertical shafts are shown to indicate that the ducts 53 radiating therefrom are preferably formed, as illustrated in FIG. 2, as large bore shafts.

The total array of retort by-product collection wells, in addition to serving the function of transferring organic by-products of the in-situ retorting process to the surface, also provide a significant driving force, in the form of pressure gradients, that contribute to the establishment and stability of forced convective heat transfer cells.

During Phase I of the present invention a carbon residue of sand-coke will be formed as a by-product of the thermal retorting of the bitumen, which coke will have a relatively high permeability to gases and liquids. In the process of pyrolyzing bitumen, as described above, therefore, a high permeability sand-coke blanket consisting of residual carbon-rich particles dispersed within the original formation matrix material will be continually formed. The sand-coke blanket, in the process of its formation, will grow continuously laterally and upwardly toward the top of the tar sand formation. Such occurrence of high permeability sand-coke will provide for a continuing enhancement in the ease of passage of liquids and gases and thereby continuously contributes to an enhancement in the effectiveness and stability of the described forced convective heat transfer cells. The described sand-coke blanket is formed without the need for combusting bitumen by forced passage of a combustion-supporting gas such as air or oxygen, and therefore, the spatial distribution of the sand-coke layer will be controlled by the formation and spatial distribution of the convection cells and not by permeability discontinuities within the virgin tar sand formation that could significantly influence the initial combustion of bitumen when such combustion has been supported by air or oxygen injection. Since the mobilized bitumen is forced to flow towards the by-product collection wells as described in this invention, the spatial distribution of residual sand-coke is more uniform, shown as a layer labeled S-C in FIGS. 4 and 7.

Once a significant layer of sand-coke has been established by operations identified and described hereinabove as Phase I of the processes, and as controlled by the duration of the initial pyrolysis period, air or oxygen may be injected, as a second phase, or Phase II of the process of the present invention, via the heating duct arrays, to ignite that coke and thereby utilize heat therefrom to supply an increment of the heat energy input to the tar sand formation so as to favorably impact the overall process economics. The addition, in Phase II, as illustrated in FIG. 7, of a combustion-supporting gas is preferably accomplished by adjusting the composition of the heating gases to include an air flow as illustrated by arrows A in FIG. 7, as necessary in those cases where a primary form of heating is via a discharge of hot gas into the heating ducts 41, or into the gas burners 42 placed within the heating ducts 41. In those cases where, in lieu of burners 42, electrical heaters, not shown, are placed within the heating ducts 41, addition of the combustion supporting gas, preferably in air flow, would be accomplished by injecting said gases into the heating ducts.

As illustrated in FIG. 7, deep collection wells 43 that are completed adjacent to line source heating ducts 41, will be surrounded with a coke blanket build up, identified as S-C. Such sand-coke will be characterized by high lateral and vertical permeability to liquids and gas. To burn, as described, that coke blanket, operation of line source heaters 42 will be temporarily suspended, and the above-described oxygen-containing gas flow, such as air, will be passed thereto. With the introduction of the air flow thereto, by virtue of the prior extraction of carbonaceous material, the coke will ignite and continue to burn as long as the air flow is maintained. The burning of the sand-coke blanket results in generation of sufficient heat to drive the forced convective heat transfer system and the pyrolysis of virgin bitumen. The by-products of the bitumen pyrolysis are collected by the shallow wells 44 completed in the upper one-third (⅓) of the tar sand formation, and the pressure gradients imposed by operation of these shallow collection wells will help to drive the convective heat transfer system. In the basal portion of the tar sand formations, a high permeability clean sand zone will therefore grow both laterally and upward as the coke is combusted the breakthrough of injected air to any collection well indicating a combustion of that coke layer and signaling a discontinuance of the air flow to avoid combustion of the bitumen. Thereafter, a subsequent reinitiation of Phase I processing will result in efficient reestablishment of the forced convective heat transfer system in part due to the presence of the clean sand zone. The Phase I/Phase II sequencing can be repeated as necessary until the desired level of carbonaceous material pyrolytic conversion and recovery of retorted by-products has been achieved.

The concepts disclosed herein describe the present invention in the context of pyrolysis of carbonaceous material contained within a typical tar sand formation and include provisions for simultaneous recovery of retorting liquid and gaseous by-products and immediate use of recovered non-condensible gases and make-up heating gas. Additionally, the concept of operation of conventional stationary horizontal to near horizontal or inclined line source heaters within a subterranean formation to the establishment of a forced-convective heat transfer system, may also be applied and practiced with good effect within other carbonaceous material bearing formation such as in oil shale formations and so the present disclosure should not be taken as limited to in-situ retorting of tar sands only. Thereafter, while a preferred method of in-situ retorting of carbonaceous material for recovery of organic liquids and gases has been shown and described herein, it should be understood that the present disclosure is made by way of example only and that variations are possible without departing from the subject matter coming within the scope of the following claims, which claims we gard as our invention.

What is claimed is:

1. A method of in-situ retorting of carbonaceous material for recovery of organic liquids and gases comprising the steps of,

in a carbonaceous material bearing formation forming heating ducts within a basal section thereof that connect to ground surface;

operating heating devices in said ducts to deliver a controlled heat into the formation to create a zone of pyrolysis that extends into the formation from the heating ducts without (causing) igniting the virgin bitumen (of formation to burn);

drawing and collecting through collection wells carbonaceous liquids and condensible and non-condensible gases cracked from the bitumen at the zone of pyrolysis interface;

injecting a combustion supporting gas flow through said heating ducts into a coke layer that (results) has resulted from the thermal cracking of the (bitumen, burning that) bitumen, the presence of which combustion supporting gas causes ignition of that hot coke, the coke then burning as a source of heat energy to the zone of pyrolysis;

terminating the combustion supporting gas flow; and

restoring operation of the heating devices to deliver controlled heat into the formation.

2. A method as recited in claim 1 wherein,

the heating devices receive a combustible gas that is burned therein.

3. A method as recited in claim 2 further including,

mixing the non-condensible gas drawn and collected with the combustible gas going to the heating devices.

4. A method as recited in claim 1, wherein,

the heating ducts are formed parallel to the dip of the formation from an outcrop thereof.

5. A method as recited in claim 1, wherein

the heating ducts are constructed to radiate outwardly in in-seam drafts from vertical shafts constructed by mining methods.

6. A method as recited in claim 1, wherein,

the heating ducts are directionally drilled well bores eminating from a control drilling pad.

7. A method as recited in claim 1 wherein the collection wells are formed as,

deep wells (and) that extend from the surface into a lower one-third of the carbonaceous material bearing formation; and

shallow wells (are formed from the surface to) that extend from the surface into an upper one-third of the carbonaceous material bearing (information) formation.

8. A method as recited in claim 7, further including,

locating the deep colection wells immediately adjacent to the heating ducts.

9. A method as recited in claim 1, further including,

burning the collected non-condensible gases as a source of heat energy to the heating devices.

10. A method as recited in claim 1, wherein the combustion supporting gas is air.

11. A method as recited in claim 1, wherein the combustion supporting gas is oxygen.

* * * * *

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Alberta OIL SANDS INFORMATION CENTRE

United States Patent [19] **Mullins et al.**

[11] **4,385,662**

[45] **May 31, 1983**

[54] METHOD OF CYCLIC SOLVENT FLOODING TO RECOVER VISCOUS OILS

[75] Inventors: **Lynn D. Mullins**, DeSoto; **John L. Fitch**, Dallas, both of Tex.

[73] Assignee: **Mobil Oil Corporation**, New York, N.Y.

[21] Appl. No.: **308,754**

[22] Filed: **Oct. 5, 1981**

[51] **Int. Cl.**^{3} **E21B 43/22**

[52] **U.S. Cl.** **166/263**; 166/50; 166/274

[58] **Field of Search** 166/263, 268, 272, 274, 166/50

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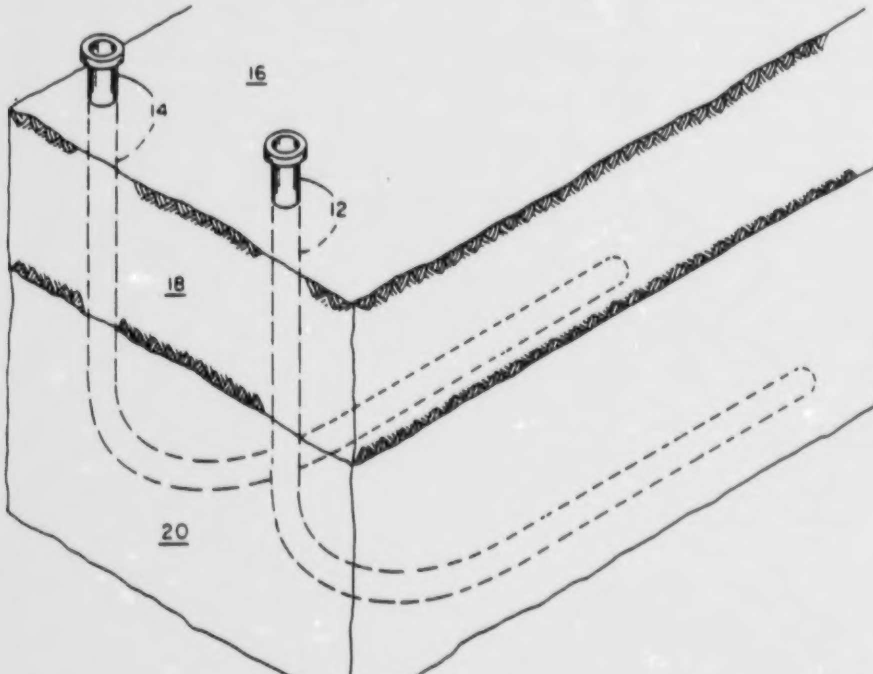
Primary Examiner—Stephen J. Novosad
Assistant Examiner—George A. Suchfield
Attorney, Agent, or Firm—Charles A. Huggett; James F. Powers, Jr.; Lawrence O. Miller

[57] ABSTRACT

Oil may be recovered from viscous oil-containing formations including tar sand deposits by providing at least one injection well and at least one spaced-apart production well which extend downwardly from the surfaces and which extend to, and generally horizontally through, the bottom of the oil-containing formation with fluid communication of the horizontally extending portions of each well with the oil-containing formation. Solvent is injected into the injection well and fluids including oil are recovered from the production well until the fluid recovered contains an unfavorable amount of solvent, preferably at least 90 percent. After injection of the solvent is terminated, both the injection well and the production well are shut-in and the formation is allowed to undergo a soak period for a predetermined time, preferably for a time of between 2 to 20 days per foot of formation thickness. After the soak period, solvent is injected into the production well and fluids including oil are recovered from the injection well until the fluid recovered contains an unfavorable amount of solvent, preferably at least 90 percent. After injection of the solvent into the production well is terminated, both wells are shut-in and the formation is allowed to undergo a second soak period for a predetermined time, preferably for 2 to 20 days per foot of formation thickness. Thereafter, a driving fluid is injected into the formation via the injection well to effect a fluid drive of the oil through the formation and oil is produced from the production well until the oil being produced contains an unfavorable amount of driving fluid, preferably at least 90 percent.

18 Claims, 3 Drawing Figures



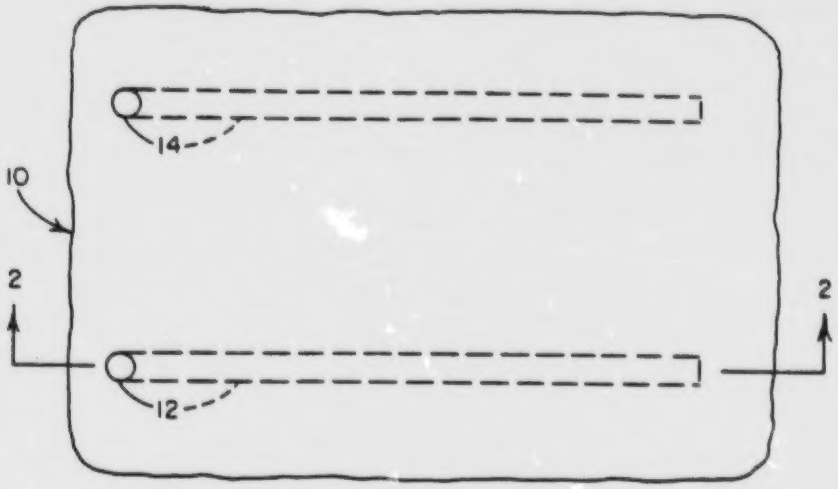


FIG. 1

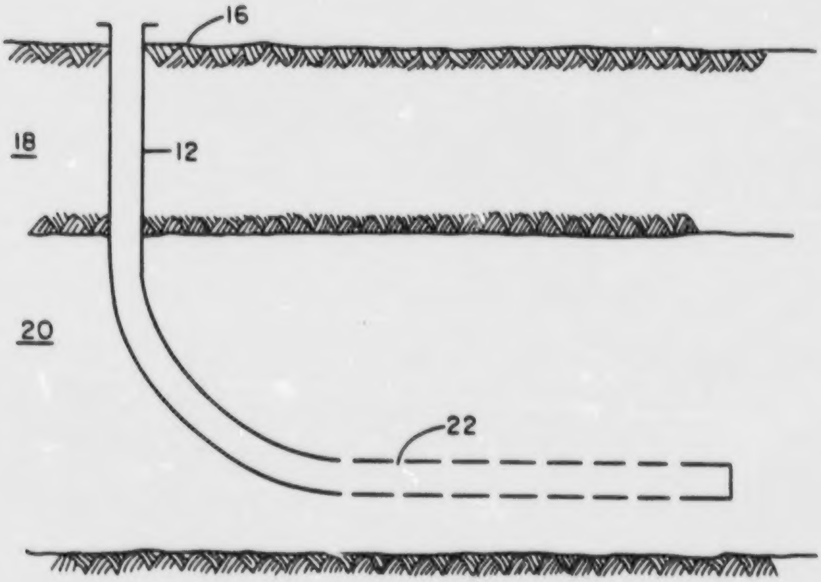

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FIG. 2

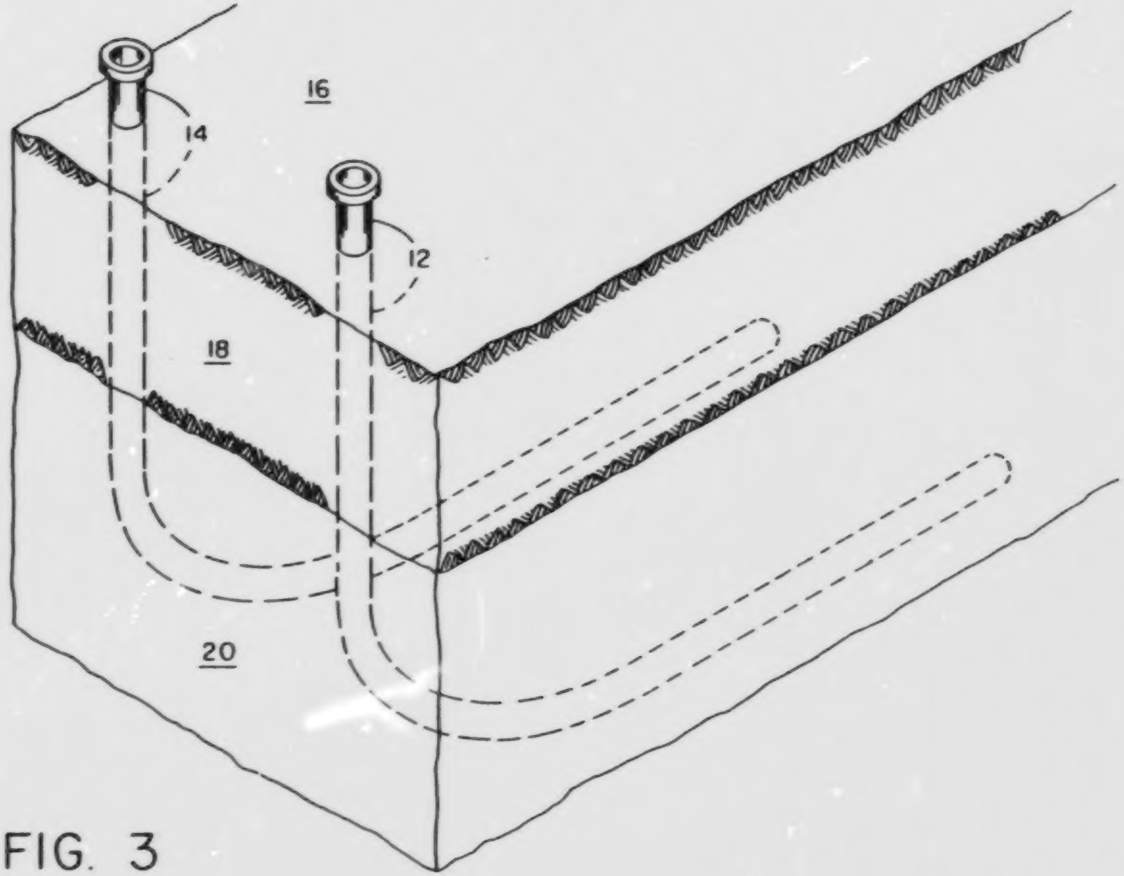
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FIG. 3

METHOD OF CYCLIC SOLVENT FLOODING TO RECOVER VISCOUS OILS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is directed to a method of recovering oil from viscous oil-containing subsurface formations. More particularly, this invention is directed to a cyclic hydrocarbon solvent recovery method for recovering oil from subsurface formations that are penetrated by at least one injection well and one production well which extend downwardly from the surface of the earth into the bottom of the oil-containing formation and then extend horizontally through the formation.

2. Description of the Prior Art

In co-pending application filed July 21, 1981 Ser. No. 285,696, now U.S. Pat. No. 4,373,585, to Fitch et al., there is disclosed a method of recovering viscous oil from a viscous oil-containing formation wherein a selected solvent is injected into a fluid communication path in the power portion of the formation intermediate at least an injection well and a production well. A hydrocarbon solvent having a density less than oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions is injected into the communication path and fluids including oil are recovered from the production well until the fluid recovered contains an unfavorable ratio of oil to solvent. The production well is shut-in and an additional quantity of the hydrocarbon solvent is injected into the fluid communication path, preferably until a total amount of between 0.05 to 0.30 pore volume has been injected. The injected well is then shut-in along with the production well to permit the formation to undergo a soak period for a variable time, preferably for a time of between 2 to 20 days per vertical thickness in feet of oil-containing formation. A driving fluid such as water is then injected into the formation via the injection well and the oil is produced until there is an unfavorable ratio of oil to driving fluid. During the fluid drive recovery phase, the injection well and production well may be completed to be in fluid communication with the entire portion of the formation to obtain a more uniform displacement of the upgraded formation oil by the driving fluid.

In co-pending application Ser. No. 46,275, now U.S. Pat. No. 4,293,035 filed June 7, 1979, to John L. Fitch, there is disclosed a method of recovering viscous oil from a viscous oil-bearing subsurface formation wherein a solvent is injected into a high mobility channel formed in the bottom of the formation intermediate an injection well and a production well. The solvent is injected until the ratio of produced oil to solvent becomes unfavorable and thereafter the injection of solvent is terminated and gas is injected into the high mobility channel to produce solvent and oil from the formation.

In U.S. Pat. No. 3,838,738 there is described a method for recovering viscous petroleum from petroleum-containing formations by first establishing a fluid communication path low in the formation. A heated fluid is then injected into the fluid communication path followed by injecting a volatile solvent such as carbon disulfide, benzene or toluene into the preheated flow path and continuing injecting the heated fluid and recovering fluids including petroleum from the production on well.

In U.S. Pat. No. 3,500,917 there is disclosed a method for recovering crude oil from an oil-bearing formation having a water-saturated zone underlying the oil-saturated zone. A mixture of an aqueous fluid which has a density greater than the density of the crude oil and a solvent having a density less than the density of the crude oil are injected into the water-saturated zone and oil is produced from the formation.

U.S. Pat. No. 4,026,358 discloses a method for recovering heavy oil from a subterranean hydrocarbon-bearing formation traversed by at least one injection well and one production well wherein a slug of hydrocarbon solvent in amounts of 0.1 to about 20 percent of the formation pore volume and having a gas dissolved therein is injected into the formation via the injection well. Thereafter, a thermal sink is created in the formation by in-situ combustion or by injecting steam. The wells are then shut-in for a predetermined time to permit the formation to undergo a soak period, after which production is continued. Optionally, after the production period, the formation may be water flooded to recover additional oil from the formation.

SUMMARY OF THE INVENTION

This invention is directed to a method of recovering viscous oil from a viscous oil-containing formation that has no significant vertical permeability barrier in the portion of the formation being produced involving at least one injection well and at least one spaced-apart production well that penetrate the formation and then extend horizontally through the bottom of the formation for cyclic injection of solvent into the formation and recovery of oil from the formation. The injection well and production well are drilled into the formation extending downwardly from the earth's surface to the bottom of the oil-containing formation and then a substantial distance through the formation in a generally horizontal direction. That portion of the injection well and production well that extends horizontally through the bottom of the formation is perforated or otherwise equipped to provide fluid communication between both wells and the formation. The production well is spaced-apart from the injection well but the horizontal portion of the production well is at the same level as, and parallel to, the horizontal portion of the injection well. A hydrocarbon solvent having a viscosity not greater than 1/100 the viscosity of the oil contained in the formation and a specific gravity less than the oil contained in the formation under formation conditions, is injected into the bottom of the formation via the injection well and fluids including oil are recovered from the production well until the produced fluid contains an unfavorable amount of solvent, preferably at least 90 percent. When this occurs, injection of solvent is terminated and both the injection well and production well are shut-in for a predetermined period of time to allow the formation to undergo a soak period. The soak period is preferably for 2 to 20 days per foot of vertical thickness of the oil-containing formation. During this soak period, the light hydrocarbon solvent will tend to rise and the heavy oil will move downward in a gravity-driven convection process forming a pattern of fingers. This fingering causes a more effective contact between the oil and solvent thereby allowing the two to mix more effectively, thus providing a greater volume of oil that is reduced in viscosity. After the soak period, the hydrocarbon solvent is injected into the bottom of the formation via the production well and fluids including oil and solvent are recovered from the formation via the injection well until the fluid being produced contains an unfavorable amount of solvent, preferably at least 90 percent. In another embodiment of the invention, following completion of the soak period, the fluid produced from the injection well which is primarily solvent is re-injected or recycled into the formation via the production well in place of pure solvent until the amount of solvent in the produced fluid is less than 90%. Thereafter, recycle of the produced fluid is terminated and pure hydrocarbon solvent is injected into the formation via the production well and production of fluids from the injection well continued until the fluid being produced contains an unfavorable amount of solvent, preferably at least 90 percent. After injection of solvent into the production well is terminated, both wells are shut-in to allow the formation to undergo a second soak period for a predetermined period of time, preferably for 2 to 20 days per foot of formation thickness. Thereafter, a driving fluid such as water is injected into the injection well to displace the mixture of oil and solvent toward the production well for recovery. Production is continued until the fluid including oil recovered from the production well contains an unfavorable ratio of oil to driving fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic plan view of an area which overlies an oil-containing formation, and it indicates by dotted lines an injection well and a production well which extends downwardly from the surface to the bottom of the oil-containing formation.

FIG. 2 is a sectional view through the area shown in FIG. 1 and it is taken along the plane indicated by the lines 2—2 in FIG. 1 showing the manner in which the injection well and production well penetrate the formation.

FIG. 3 is an isometric view of a rectangular block of the earth showing the position of the injection well and the producton well within the formation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention relates to a hydrocarbon solvent recovery method for recovering viscous oil from a viscous oil-containing subsurface formation that has no significant vertical permeability barrier in the portion of the formation to be treated utilizing injection and production wells which extend from the earth's surface downwardly into the oil-containing formation and then extend horizontally through the lower portion of the oil formation. Viscous oil is a term used to identify oil having relatively high viscosity and includes those oils referred to as tars. Such viscous oils are also referred to as heavy oils. In general, the term viscous oil is used to include those heavy oils and tars such as are commonly found in formations referred to as heavy oil or tar sands that have viscosities that are great enough to severely restrict the production of the oils from the formations in which they are found. The API gravity of such viscous oils is normally 20° API or less.

Referring to FIG. 1, a field 10 overlying an oil-containing formation is provided with an injection well 12 and a production well 14. As shown in FIGS. 2 and 3, the injection well 12 and the production well 14 extend downwardly from the earth's surface 16, through an overburden 18, into the oil-containing formation 20 and then extend horizontally through the bottom of the formation. The production well 14 is spaced apart from the injection well 12 and the horizontal portion of the production well is at the same level and parallel to the horizontal portion of the injection well. The horizontally extending portion of the injection well 12 and the production well 14 have perforations 22 providing fluid communication between that portion of each well and the lower portion of the formation 20. Although only one injection well and one production well are shown for purposes of illustration, it is understood that a plurality of alternating spaced apart injection wells and production wells may be used in our process with the number depending upon the characteristics of the oil-containing formation. The wells may be formed by conventional directional drilling means with the horizontally extending portion of each well in the bottom of the formation being within plus or minus 20° of a horizontal plane.

A hydrocarbon solvent having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions is injected via the injection well 12 and fluid including oil is recovered from the formation via production well 14. Solvent injection is continued until the fluid being produced from the formation by means of production well 14 comprises an unfavorable amount of solvent, preferably at least 90 percent.

Thereafter, injection of the solvent is discontinued and both the injection well 12 and production well 14 are shut-in to allow the formation 20 to undergo a soak period for a variable time, preferably for a period of time between 2 to 20 days per foot of the vertical thickness of the oil-containing formation. It will be recognized by those skilled in the art of oil recovery that during this shut-in or soak period minor amounts of fluid may be injected or produced, such as for the purpose of testing, without significant detrimental effects on the process. During the soak period, the liquid hydrocarbon solvent being lighter than the oil contained in the viscous oil-containing formation, that is, having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions, will tend to flow by gravity-driven convection upward into the oil-containing formation and the heavy oil will flow by gravity-driven convection downward forming a pattern of fingers. This fingering is important in that the distribution, size and extension of these fingers will provide intimate contact between the solvent and the heavy oil allowing the two to mix more effectively, thus forming a greater volume of oil that is reduced in viscosity and which can be produced more readily.

Once the soak period has been completed, hydrocarbon solvent is injected into the formation via the production well 14 and fluid including oil is recovered from the formation via the injection well 12. Solvent injection is continued until the fluid being recovered from the formation by means of the injection well 12 comprises an unfavorable amount of solvent, preferably at least 90 percent. Thereafter, production of fluids from the formation by means of injection well 12 is terminated and both the injection well 12 and producton well 14 are shut-in for a predetermined period of time to allow the formation to undergo a second soak period. The second soak period is preferably 2 to 20 days per foot of formation thickness being treated.

When the injection well is placed on production at the end of the first soak period, the produced fluid will consist primarily of solvent. Therefore, in another embodiment of our process to permit maximum solvent usage together with minimizing the quantity required, the fluid recovered from the injection well after the first soak period is re-injected or recycled into the formation via the production well 14 in place of pure solvent until the amount of solvent in the fluid produced from the injection well is less than 90%. Once the solvent content of the produced fluid drops to less than 90%, recycle of this fluid is terminated and pure solvent is injected into the production well. Injection of the pure solvent is then continued until the amount of solvent in the fluid being produced from the formation by means of injection well 12 contains an unfavorable amount of solvent, preferably at least 90 percent.

The above sequence of solvent injection, production and soak period followed by repeating these steps after convering the production well to an injection well and the injection well to a production well may be repeated for as many cycles as is desired.

Thereafter, a driving fluid is injected into the formation 20 via the injection well 12 which displaces the oil of reduced viscosity from the formation into the production well 14 and production is continued until the recovered fluid contains an unfavorable amount of driving fluid, preferably at least 90 percent. The driving fluid for use in our process may be gaseous or liquid and is preferably an aqueous fluid. Suitable gaseous driving fluids include light aliphatic hydrocarbons having from one to four carbon atoms, carbon dioxide or nitrogen. Suitable aqueous fluids include water, brine or thickened water.

The hydrocarbon solvents used in our process must have a specific gravity less than that of the oil and less than that of the brine injected or naturally present in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions. It is also highly desirable that the hydrocarbon solvent remain liquid under the temperature and pressure conditions that exist in the subsurface viscous oil-containing formation and not cause solids such as asphaltenes to precipitate from the oil in amounts sufficient to seriously plug the pores of the formation. The preferred hydrocarbon solvent is a light crude oil. Other examples of suitable hydrocarbon solvents include light oil condensates having an API gravity greater than 30 API degrees and partially refined tar which is generally known as syncrude. It may be desirable to include in the hydrocarbon solvent up to about 10 percent of aromatic material such as aromatic refinery stock to make the solvent compatible with the oil contained in the formations and to prevent the deposition of solid or gelatinous materials such as asphaltenes therefrom.

The viscous oil-containing subsurface formation to be treated by the present hydrocarbon solvent recovery method must be one that has no significant vertical permeability barriers in that portion of the formation to be treated. This allows the solvent that is injected into the bottom of the formation between the injection well and production well to flow upward into the formation by convection forces thus solubilizing the oil and forming a solvent-oil mixture of reduced viscosity that can be more readily produced.

In a further embodiment, the injection well and the production well may extend downwardly from the earth's surface into the bottom of the oil-containing formation with the lower portion of each well extending through the formation at a downward angle not greater than 20° relative to a horizontal plane and the lower portion of each well in fluid communication with the formation. The production well is spaced apart from the injection well and the lower portion is at the same level and parallel to the lower portion of the injection well.

What is claimed is:

1. A method of recovering viscous oil from a subterranean viscous oil-containing formation having no significant vertical permeability barrier therein comprising the steps of:

(a) providing at least one injection well extending downwardly from the earth's surface to the bottom of said oil-containing formation wherein the lower portion of the well extends through the formation at a downward angle not greater than 20° relative to a horizontal plane;

(b) providing at least one production well extending downwardly from the earth's surface to the bottom of said oil-containing formation wherein the lower portion of the well extends through the formation at a downward angle not greater than 20° relative to a horizontal plane;

(c) said production well being spaced from said injection well but the lower portion of said production well being generally at the same level as, and being generally parallel to, the lower portion of said injection well;

(d) said injection well and said production well being in fluid communication with the lower portion of said formation;

(e) injecting a hydrocarbon solvent into the formation via said injection well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil and solvent from the formation via the production well until the fluid being recovered comprises an unfavorable amount of solvent;

(f) shutting-in said wells to permit said formation to undergo a soak period for a predetermined period of time;

(g) thereafter injecting a hydrocarbon solvent into the formation via said production well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil and solvent from the formation via the injection well until the fluid being recovered comprises an unfavorable amount of solvent;

(h) shutting-in said wells to permit said formation to undergo a soak period for a predetermined period of time; and

(i) thereafter injecting a driving fluid into the formation via said injection well and recovering fluids including oil from said formation via said production well until the fluid being recovered from the production well comprises an unfavorable amount of driving fluid.

2. The method of claim 1 wherein steps (e) through (h) are repeated for a plurality of cycles.

3. The method of claim 1 wherein the soak period during steps (f) and (h) is for a period of time between 2 and 20 days per foot of vertical thickness of the oil-containing formation.

4. The method of claim 1 comprising the additional step following step (f) of producing fluid including oil and solvent from the formation via said injection well and re-injecting said fluid into the formation via said production well until the amount of solvent in said fluid is less than 90 percent.

5. The method of claim 1 wherein the driving fluid is a gaseous material selected from the group consisting of carbon dioxide, nitrogen or aliphatic hydrocarbons having one to four carbon atoms.

6. The method of claim 1 wherein the driving fluid is water.

7. The method of claim 1 wherein said hydrocarbon solvent is selected from the group consisting of a light crude oil having an API gravity greater than 30 API degrees and a light crude oil product generally known as syncrude.

8. The method of claim 1 wherein the production of fluids from the formation according to steps (e) and (g) is continued until the recovered fluids contain at least 90 percent solvent.

9. The method of claim 1 wherein the production of fluids from the formation according to step (i) is continued until the recovered fluids contain at least 90 percent driving fluid.

10. A method of recovering viscous oil from a subterranean viscous oil-containing formation having no significant vertical permeability barrier therein comprising the steps of:

(a) providing at least one injection well extending downwardly from the earth's surface to the bottom of said oil-containing formation and then extending a substantial distance through said formation in a generally horizontal direction;

(b) providing at least one production well extending downwardly from the earth's surface to the bottom of said oil-containing formation and then extending a substantial distance through said formation in a generally horizontal direction;

(c) said production well being spaced from said injection well but the generally horizontal portion of said production well being generally at the same level as, and being generally parallel to, the generally horizontal portion of said injection well;

(d) said injection well and said production well being in fluid communication with the formation over the distance of each well extending through said formation in a generally horizontal direction;

(e) injecting a hydrocarbon solvent into the formation via said injection well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil and solvent from the formation via the production well until the fluid being recovered comprises an unfavorable amount of solvent;

(f) shutting-in said wells to permit said formation to undergo a soak period for a predetermined period of time;

(g) thereafter injecting a hydrocarbon solvent into the formation via said production well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil and solvent from the formation via the injection well until the fluid being recovered comprises an unfavorable amount of solvent;

(h) shutting-in said wells to permit said formation to undergo a soak period for a predetermined period of time; and

(i) thereafter injecting a driving fluid into the formation via said injection well and recovering fluids including oil from said formation via said production well until the fluid being recovered from the production well comprises an unfavorable amount of driving fluid.

11. The method of claim 10 wherein steps (e) through (h) are repeated for a plurality of cycles.

12. The method of claim 10 wherein the soak period during steps (f) and (h) is for a period of time between 2 and 20 days per foot of vertical thickness of the oil-containing formation.

13. The method of claim 10 comprising the additional step following step (f) of producing fluid including oil and solvent from the formation via said injection well and re-injecting said fluid into the formation via said production well until the amount of solvent in said fluid is less than 90 percent.

14. The method of claim 10 wherein the driving fluid is a gaseous material selected from the group consisting of carbon dioxide, nitrogen or aliphatic hydrocarbons having one to four carbon atoms.

15. The method of claim 10 wherein the driving fluid is water.

16. The method of claim 10 wherein said hydrocarbon solvent is selected from the group consisting of a light crude oil having an API gravity greater than 30 API degrees and a light crude oil product generally known as syncrude.

17. The method of claim 10 wherein the production of fluids from the formation according to steps (e) and (g) is continued until the recovered fluids contain at least 90 percent solvent.

18. The method of claim 10 wherein the production of fluids from the formation according to step (i) is continued until the recovered fluids contain at least 90 percent driving fluid.

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(54) METHOD AND APPARATUS FOR RECOVERING HIGH VISCOSITY OILS

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METHOD AND APPARATUS FOR RECOVERING HIGH VISCOSITY OILS

RELATED PATENT APPLICATIONS

This application is related in part to Canadian Patent Application No. 334,159, filed August 21, 1979. (Sec. M-9 - Cl. 166- Sub. Cl. 34)

BACKGROUND OF THE INVENTION

This invention relates to methods and apparatus for recovering high viscosity oil from subsurface earth formations, and more particularly relates to improved methods and apparatus for recovering such oils by employing a large diameter shaft hole and a plurality of drill holes extending radially from the shaft hole.

Early disclosures relating to the recovery of petroleum substances by utilizing a large diameter shaft hole and a plurality of drill holes are provided in U.S. Patent Nos. 1,520,737 and 1,634,235, and a paper published by Ranney in the Petroleum Engineer in 1939 entitled "The World's First Horizontal Hole." These publications propose the drilling of a large diameter shaft into an oil-bearing formation and then drilling radial drill holes into the formation. More recently, U.S. Patent Nos. 4,020,901, 4,099,570, 4,099,783 and 4,160,481 provide improved systems for recovering petroleum substances employing large diameter shaft holes and radials. The above processes, however, suffer limitations relating to restrictions on the rate of introducing the injection fluid, and the overall efficiency of the oil recovery process according to the above techniques may be so poor that recovery of the oil is not economically feasible.

The publication and patents referred to above teach that steam or other heated fluids can be injected into horizontal drill holes or laterals extending from a large diameter shaft hole. The steam or other heated injection fluid is introduced via laterals into the formation in order to provide heat to the formation and thus reduce viscosity of the oil. The heated oil thereafter flows to recovery laterals, being assisted by gravity.

The above procedure is generally referred to as a "soak" operation, which should be distinguished from a "drive" operation. In a "soak" operation, the injected fluid is intended to lower the viscosity of the oil and thereby enable the oil to more freely flow toward recovery lines by gravitational forces. A soak operation may be enhanced by raising the pressure in the formation and assisting the recovery of oil by increasing the differential between the formation pressure and the pressure at the point of recovery.

It is also common practice to inject fluid into a conventional vertical well for the purpose of driving oil within a formation horizontally to be recovered by a distant vertical well. In this "drive" operation, injected fluid is intended to act as a vertical bank or wall in the formation and push or drive the oil horizontally toward the recovery well. Although the drive operation may be enhanced by injecting either a heated fluid or a solvent to additionally lower the viscosity of the oil, the injected fluid is ideally acting as a piston head to move through the formation and drive the oil toward the point of recovery. Horizontal drive often results in viscous fingering and/or gravity override which are very detrimental to a horizontal drive operation.

Horizontal drive operations are therefore generally concerned with the "critical velocity" of the injected fluid, so that the driving force does not break down as a result of viscous fingering or gravity override. Since the fluid injected in horizontal drive operations is preferably introduced at rates to keep the driving operation below the critical velocity, the recovery rate, and the corresponding economics of this operation, are often unacceptable. Both phenomena commonly referred to as viscous fingering and gravity override, as well as the differences between "soak" and "drive" operations, are more fully discussed in my copending application, Serial No. 334,159.

It is also well-known to inject water via conventional vertical bore holes into the bottom of an oil-bearing formation, while producing oil from conventional vertical bore holes near the top of the formation. In this procedure, often referred to as conventional vertical flooding, the oil is displaced vertically upward by the injected water. By using conventional vertical bore holes terminating near the top of the formation and conventional vertical bore holes terminating near the bottom of the formation, it is also known that low viscosity oils can be collected by injecting a light hydrocarbon in the top of the formation while recovering the light oil from the vertical bore hole terminating at the bottom of the formation. In the latter procedure, the light oil is pushed downward by the lighter hydrocarbon. The recovery of oil utilizing conventional vertical wells and drive techniques are often poor, however, because a limited number of points of recovery are provided by the vertical wells.

These conventional techniques have several inherent problems. In order to properly "blanket" an area prior to establishing active horizontal driving displacement of the oil, the displacing fluid must be injected at a low rate. Also, if effective blanketing is to be achieved, the formation must have high permeability and the difference in density between the oil and the injected fluid should be high. If a good blanket of injecting fluid is not formed, or if a good blanket is formed but the displacing fluid is injected at too high a rate, viscous fingering can result. When this condition occurs, the injecting fluid no longer effectively displaces the oil, and the volumetric sweep efficiency of the operation falls off drastically.

In order to minimize the likelihood of viscous fingering when utilizing the prior art techinques, the injecting fluid is often introduced into the formation at low injection rates, e.g., 400 barrels of fluid per day per well. Optimum steam injection rates with vertical wells are more fully discussed in an article by Messrs. Bursell and Pittman, appearing in the Journal of Petroleum Technology, August, 1975, beginning on page 997. Low injection rates, of course, generally result in low production rates, which significantly increases the cost of production.

The problems and disadvantages of the prior art are overcome with the present invention. Novel methods in apparatus are hereinafter provided for recovering high viscosity oils from sub-surface formations, wherein a greater percentage of the oil can be recovered from the formation and can be recovered in a more efficient manner.

SUMMARY OF THE INVENTION

In one embodiment of this invention, a vertical mine shaft of sufficient diameter to accommodate personnel and equipment is bored to and through a formation containing a high viscosity oil. The vertical shaft is enlarged near the top of the formation and near the bottom of the formation forming chambers to provide increased space for men and equipment. Substantially horizontal drill holes or laterals are thereafter bored radially into the formation. The numbering and spacing of these laterals will be discussed in detail below. For the present, it is significant that one group of laterals is provided near the top of the formation, and another group of laterals is provided near the bottom of the formation. Each group or set of boreholes or laterals effectively blankets a particular portion of the formation, and the configuration of each blanket may be rectangular. Thereafter, drill holes are bored into the face of the formation and radially about the chamber, through which a suitable fluid is thereafter injected into the formation by way of a conduit leading to the surface.

Using the above-described apparatus with one set of laterals near the top of a formation and another set at the bottom of a formation, oil may be recovered by either (a) introducing an injected fluid into the bottom set of laterals while recovering oil from the top set of laterals, or (b) introducing an injected fluid into the top set of laterals while recovering oil from the bottom set of laterals.

The instant invention preferably utilizes a plurality of substantially horizontal laterals which are drilled in the formation for recovery of high viscosity oil through "drive" techniques, while the prior art attempts to improve oil recovery by using boreholes or laterals within the formation and various "soak" techniques. In the present invention, the driving force of the injected fluid is substantially vertical: vertical upward drive toward the top set of laterals, or vertical downward drive toward the bottom set of laterals. The advantage of driving vertically rather than horizontally, as taught by conventional oil recovery techniques, is that the injected fluid may be introduced at a much higher rate because the likelihood of viscous fingering is substantially reduced and detrimental gravity override is eliminated. A fluid may therefore be injected according to the present techniques at rates equivalent to the maximum output of most commercial generators, without regard to the concept of critical velocity, fingering, or gravity override.

In conventional oil wells, it is often quite difficult to establish a blanket of injected fluid, although the fluid is injected at various points in the plane of the blanket. According to the present invention, the blanket of injected fluid may be more easily established since the fluid is not injected at points in the blanket, but rather is injected along entire lines lying within the blanket. These lines effectively provide a multitudinous number of points of injection so that the blanket for the drive operation is more easily established.

As previously mentioned, the apparatus described may be utilized for vertical upward drive or vertical downward drive. This offers a distinct advantage over the prior art since the injected fluid can be selected for either upward or downward drive depending on the density of the oil in the formation, the desirability of using a miscible or an immiscible injected fluid, the availability of the injected fluid, and the particuler characteristics of the formation. For instance, if the oil in the formation is a heavy crude oil, e.g., 14° API, and a relatively heavy injected fluid is available, e.g., carbon disulfide, vertical upward drive of the oil is feasible. Thus, carbon disulfide, may be injected in the bottom set of laterals, and, since the injected fluid is heavier than the oil, it would not tend to rise naturally in the formation. A blanket of injected fluid may be thereby easily established in the bottom of the formation. As the injection of carbon disulfide continues, the injected fluid drives oil upward in the formation toward the top set of laterals. Fluid may continue to be injected in the bottom set of laterals while oil is recovered from the top set of laterals, until the injected fluid is effectively driven through the entire formation.

If, on the other hand, the formation pressure is high and heated water is readily available as an injected fluid, downward vertical drive may be desirable. Heated water at 500° F. is less dense than 14° API oil. Thus, heated water may be injected in the top set of laterals serving to drive the oil downward for recovery by the bottom set of laterals. In this manner, a blanket of injected fluid is established in the upper portion of the formation, and the oil is driven downward by the continued injection of fluid.

The particular spacing and arrangement of drill holes will, of course, depend upon the size and lithology of the formation of interest, but it is a feature of the invention to provide approximately eight different radially extending drill holes for each shaft hole, and to further extend such drill holes to a location adjacent the ends of similar radials extending from an adjacent vertical shaft hole. As will hereinafter be explained in detail, each group of radial drill holes will then define a rectangular pattern within the field, and thus the field may be effectively "covered" with a blanket of such rectangular patterns.

The bore holes or radials may extend from the large diameter shaft hole in a generally horizontal direction. Some of the radials, however, may be positioned at a slight upward angle, e.g., 3° - 7°, so that gravity may assist the flow of oil within the lateral. Also, some formations have generally horizontal barrier zones which are impermeable to fluid flow. Relatively thin shale deposits are one example of these impermeable barrier zones. When such zones exist, the bore holes or laterals may be drilled at a greater upward angle, e.g., 10° - 18° upward from the horizontal, so that the bore holes would pass through one or more of these barrier zones. Thus, the recovery of oil and the efficiency of the operation will be increased since oil can be recovered by soak or drive techniques which would have previously remained within the formation because of the presence of the impermeable barrier zones.

It is within the concept of the present invention to locate the radials adjacent the lower limit of the formation, whereby the fluid injected therefrom will also tend to rise as well as travel laterally through the formation, and also to provide additional pluralities of such radial drill holes at other higher locations within thicker formations. Furthermore, it is within the concept of this invention to inject fluid through only a portion of the radials, while also recovering oil from one or more of the other radials extending from the same shaft hole.

The invention is suitable for recovering oil from subsurface formations, and is particularly suitable for recovering high viscosity oils. High viscosity oils are generally inclusive of both medium gravity oils having an API range of 20° to 25°, and heavy crude oils having an API range of 20° or less.

A particular feature of this invention is to provide methods and apparatus that result in increased production rates for recovering high viscosity oil from subsurface earth formations.

It is another feature of this invention to provide methods and apparatus for driving oil within a subsurface earth formation vertically toward recovery laterals extending radially from a large diameter shaft hole.

It is a further feature of this invention to provide methods and apparatus that will increase the overall efficiency of recovering high viscosity oil from a subsurface earth formation by utilizing vertical drive techniques.

It is an additional feature of this invention to provide apparatus for recovering oil from a subsurface earth formation, comprising a shaft hole extending from the surface to said subsurface earth formation, a first plurality of boreholes extending radially from said shaft hole into said formation at a first elevation, a second plurality of boreholes extending into said formation at a second elevation, and injection means introducing a fluid through said second plurality of said boreholes and into said formation for driving said oil vertically for recovery by said first plurality of boreholes.

It is a further feature of this invention to provide a method of recovering oil from a subsurface earth formation, comprising establishing a shaft hole extending from the surface of the earth to said subsurface earth formation, drilling a first plurality of boreholes radially from said shaft hole into said formation at a first elevation, drilling a second plurality of boreholes into said formation at a second elevation, and injecting a driving fluid into said second plurality of boreholes and into said formation for driving said oil vertically for recovery by said first plurality of boreholes.

The method of the present invention comprises establishing a shaft hole extending from the subsurface of the earth to said subsurface formation, drilling a plurality of boreholes substantially laterally from the shaft hole into said subsurface earth formation, drilling a second plurality of boreholes, all terminated substantially at another second level, injecting into said formation through said second plurality of boreholes a displacing fluid to establish a substantially horizontal stratum of said displacing fluid, injecting into said formation through said second plurality of boreholes a driving fluid under pressure to vertically drive said stratum of said displacing fluid through said formation, and withdrawing oil from said shaft hole through said first plurality of boreholes while simultaneously injecting said driving fluid into said formation.

Also, the present invention provides for an apparatus that includes a shaft extending from the surface of the earth to said subsurface earth formation, a first plurality of boreholes extending radially from said shaft and lying within a substantially horizontal first plane within said formation at a first elevation, a second plurality of boreholes all terminated substantially at another second level and comprising fluid output means for defining a layer of fluid, injection means introducing a displacing fluid through said second plurality of boreholes to provide a layer of displacing fluid, pressurizing means introducing a driving fluid through second plurality of boreholes for driving the layer of displacing fluid vertically toward said first plurality of boreholes, and recovery means for withdrawing oil from said first plurality of boreholes.

These and other features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

IN THE DRAWINGS

Figure 1 is a simplified pictorial representation, partly in cross-section, of an exemplary installation for recovering oil from a subsurface earth formation according to the present invention.

Figure 2 is a cross-sectional representation of a portion of the apparatus depicted in Figure 1.

Figure 3 is a simplified pictorial representation, partly in cross-section, of a portion of the apparatus depicted in Figure 1.

Figure 4 is a graph illustrative of the variations in specific gravity for fluids, and is referred to in the description to assist in illustrating the concepts of the present invention.

Figure 5 is a simplified pictorial representation, partly in cross-section, of another form of an exemplary installation according to the present invention.

Figure 6 is a cross-sectional representation of a portion of the apparatus depicted in Figure 5.

DETAILED DESCRIPTION

In Figure 1, there may be seen a pictorial representation of an oil recovery system embodying the concepts of the present invention. In particular, the apparatus depicted in Figure 1 may be utilized for recovering high viscosity oil from subsurface earth formations. A substantially vertical mine shaft 2 is drilled or bored from the surface 4 to the oil-bearing formation 6. The oil-bearing formation 6 may typically be hundreds of feet below the surface 4, and is shown to be bounded by an upper layer 5 and a lower layer 7 of shale deposits, which are generally impregnable to fluid flow. As seen in Figure 1, the mine shaft 2 is drilled through the oil-bearing formation 6, and terminates at a sump hole 8.

The shaft 2 is expanded near the top portion of the formation to form an upper work chamber 10, and is expanded at the bottom portion of the formation to form a lower work chamber 12. A plurality of upper laterals 14 and 16 may be drilled into the formation 6 from the upper work chamber; a plurality of lower laterals 18 and 20 may likewise be drilled into the formation from the lower work chamber 12.

A steam generator 22 at the surface floor provides injection fluid to the upper laterals 14 and 16 by a steam line 24. If desired, a plurality of steam lines 24 may be provided, so that the injected fluid to each upper lateral may be separately controlled at the surface by conventional valving techniques. The lower laterals 18 and 20 may serve as recovery lines for oil, which is collected in recovery tank 26. Each of the lower laterals 18 and 20 may be connected to individual recovery lines 28 and 30 which may terminate at the recovery tank 26, or the recovery lines 28 and 30 may join at a subsurface manifold 32 so that oil from the various lower laterals 18 and 20 flows to the recovery tank 26 by a central recovery line 34.

Referring again to Figure 1, it may be seen that a portion of the radial or lateral 14 extending from the wall of the upper work chamber 10 may be suitably provided with a casing 36, with a perforated portion of the lateral 14 thereafter extending from the casing 36. The walls of the shaft 2 may be conveniently sealed with sections of bolted or welded steel plates to form a casing 38, or may be lined with an appropriate material such as gunite, to prevent caving or other collapse of the walls of the shaft 2. The diameter of the shaft 2 is preferably of a size sufficient to accommodate the passage of men and equipment from the surface 4 to the interior of the work chambers 10 and 12. The mine shaft 2 and each of the work chambers 10 and 12 may be constructed in the manner further described in U.S. Patent 4,160,481.

In the embodiment of this invention illustrated in Figure 1, fluid is injected into the formation via radial drill holes or laterals 14 and 16 which lie entirely within the formation 6. If the injected fluid is heated water or steam, heat loss by way of the steel casing 38 therein is not significant since the heat merely transfers to the formation. On the other hand, it is desirable for the injected fluid to enter the formation at a distance from the shaft 2 or work chamber 10, so that the fluid will tend to move outwardly therefrom instead of bypassing back into the chamber 10. Furthermore, it may be preferable to insert pre-perforated pipe or casing into the radial drill holes, rather than to perforate the casing in a conventional manner after it has been inserted. The upper laterals may contain the casing 36, but the casing is not necessary according to the present invention. Thus, although the casing 36 is only shown for the upper lateral 14, it is within the concept of my invention that the casing be employed with all, some, or none of the injection laterals.

Referring now to Figure 2, there is illustrated a cross-sectional view of the laterals shown in Figure 1. In Figure 2, four upper laterals radiate from the shaft 2 at 90° intervals, and are denoted as 14, 15, 16 and 17. Four lower laterals are also spaced at 90° intervals, and the lower laterals 18, 19, 20 and 21 are shown connected to their respective vertical recovery lines 28, 29, 30 and 31.

Both the upper set of laterals and the lower set of laterals depicted in Figures 1 and 2 lie in substantially horizontal planes. As explained in further detail below, the upper set of laterals, in combination with an injected fluid, form a blanket of injected fluid which act as the driving force for the recovery process. Typically, the laterals will radiate from the shaft 2 to enable a substantially horizontal blanket to be established having an area of 25 acres. In Figure 2, the pattern of the blanket formed by the injection radials 14, 15, 16 and 17 is circular. Other configurations are possible, and the particular configuration of the blanket formed by the injection laterals will depend, in part, on the characteristics of the formation, the viscosity of the oil in the formation, the injected fluid, and the possible use of injection laterals in combination with conventional wells. For instance, the configuration of the injection laterals may form a rectangular blanket, as shown in my co-pending patent application, which is Serial No. 334,159. The length of the laterals will depend on their relative position to one another, since the injection laterals preferably function to form a uniform substantially horizontal blanket in a portion of formation 6. Further, the diameters of the laterals will depend primarily upon the type of matrix composing the formation 6, as well as the viscosity of the oil sought to be recovered therefrom.

Figure 3 illustrates a portion of the apparatus generally depicted in Figure 1. A tubular member 40 is typically inserted into any of the boreholes described, such as the laterals 14, 15, 16 and 17 in Figure 2. Likewise, a tubular member 42 may be inserted into the laterals 18, 19, 20 and 21. The oil-bearing formation 44 is bounded on the top by a layer of shale or other rock 46, and on the bottom by a similar impregnable layer of shale or other rock 48. The layers 46 and 48 are typical of any number of materials which often exist on the upper and lower portions of an oil-bearing formation. Generally, these impregnable layers line a substantially horizontal plane, although perhaps not as uniform as the layers depicted.

As previously stated, it is preferable according to the present invention that the upper tubular member 40 be placed near the upper portion of the formation, and that the lower tubular member 42 be near the bottom portion of the formation. The exact spacing of the upper and lower laterals will possibly depend on the configuration of the layers 46 and 48. If these layers are uniform and substantially horizontal within the area of the recovery operation, the laterals may be drilled very close to the layers. If the layers are irregular in configuration, the upper laterals may be drilled in the upper fifth of the formation, and the lower laterals in the lower fifth of the formation. For example, if the formation 44 is approximately 60 feet thick and substantially uniform in configuration, the upper tubular member 40 is preferably 1 to 5 feet from the bottom of the top layer 46, and the lower tubular member 42 is preferably 1 to 5 feet above the top of the bottom layer 48.

A simplified method of operation according to the present invention will now be described by reference to Figures 1, 2 and 3. For the present, it will be assumed that steam has been selected as the injection fluid, and that both steam and water at the temperature and pressure within the formation are less dense than the oil in the formation.

Steam from the generator 22 may be injected into upper laterals 14, 15, 16 and 17 by a plurality of steam lines 24. The steam may enter the formation 44 through a series of perforations in the upper tubular members, such as the perforations 50 in the tubular member 40. The perforations 50 may be formed along the entire length of the tubular member 40, and are preferably formed along at least a substantial portion of the length of the tubular members.

Heat from the injected steam will decrease the viscosity of the oil in the formation adjacent the tubular member 40. As the formation 44 is heated, condensate may be formed which will be more dense than the steam, but less dense than the oil in the formation. The steam from the tubular member 40 will, in combination with the steam simultaneously injected in the other upper laterals, produce a blanket of steam generally in the plane of the upper laterals.

Continued injection of steam into the upper laterals will cause a pressure increase in the top of the formation 44. This pressure increase will drive the oil in the formation downward toward the lower tubular member 42. Also, the condensate from the injected steam may serve as a face for the driving force. In other words, the increase in pressure above the condensate layer will force the condensate layer downward, thus driving the oil downward from the formation.

As the steam is injected in the upper tubular member 40, oil will be simultaneously recovered through perforations 54 along a substantial portion of the length of the lower tubular member 52. Referring to Figure 2, steam injected into the upper laterals 14, 15, 16 and 17 will drive the oil downward for recovery by the lower laterals 18, 19, 20 and 21. In this manner, the oil from the formation 44 may be efficiently recovered by the downward drive of the injection fluid.

As stated above, the present invention may be effectively employed by utilizing a driving fluid and driving the oil vertically toward recovery laterals. In a vertical driving technique, the pressure gradient within the formation may be altered by the injected fluid to force the oil toward the recovery lines. Because of the weight of the oil in the formation, the pressure near the upper section of the formation will generally be less than the pressure in the lower portion of the formation. By way of illustration and referring to Figure 1, if the formation 6 were 60 feet thick and the pressure at the top of the formation just below the layer 5 was 15 psia, the pressure near the bottom of the formation above the layer 7 may typically be 40 psia because of the pressure gradient of the oil in the formation 6.

According to the vertical steam drive tecnniques discussed berein, drawing the oil from the recovery lines and injecting a fluid into the injection lines will produce a pressure differential sufficient to force or drive the oil vertically. Preferably, a pressure differential of 100 psia or more is achieved during the driving process between the pressure at the place of injection and the pressure at the place of recovery within the formation. The preferred pressure differential will vary depending on the specific characteristics of the oil and the formation, and typically a pressure differential of 200 psia to 400 psia will be desired. The maximum pressure at the place of injection is generally limited for safety reasons to 1 psig per foot of overburden. For instance, if steam is injectea into the laterals 14, 15, 16 and 17 which are 400 feet below the surface 4, it may be desired to limit the pressure provided in the upper portion of the formation 6 to 400 psia.

As previously mentioned, vertical drive may be properly utilized without concern for gravity override, even with injection rates far exceeding the injection rate employed in conventional horizontal drive. In the embodiment described above, the density contrast between the oil and the injected fluid is deliberately utilized during the driving operation to increase the efficiency of the recovery processes, while the same density contrast may result in gravity override in horizontal drive operations which is detrimental to the efficiency of horizontal drive recovery processes. Also, since the oil is being driven vertically downward, the likelihood of viscous fingering during the driving operation is substantially eliminated since (a) a uniform blanket of driving fluid is initially formed, (b) the condensate layer 52 acts as a face for driving the oil from the formation, and (c) the oil is being driven vertically downward, and the injected fluid will not tend to pierce through the formation 44 because the injected fluid is less dense than the oil below the injected fluid. Further, as explained below, viscous fingering prior to the driving operation increases the efficiency of the recovery process according to the present invention, rather than being detrimental to the recovery efficiency as in horizontal drive techniques.

Steam may be continually injected into the upper tubular member 40 until condensate or steam has been recovered from the lower tubular member 42. At this point, further injection of steam may not be economical, since little if any further oil will be recovered from the lower tubular member 42. If the vertical recovery lines 28 and 30 are used to connect each lateral to the recovery tank 26, it is possible to monitor the fluid being recovered at the surface 4 from each lower lateral. In this manner, it may be desirable to discontinue the injection of steam into the upper laterals which are adjacent the lower laterals in which steam or condensate is being recovered, while continuing to inject steam into the other upper laterals as long as oil is being produced from their respective adjacent lower laterals. If the recovered oil is either being forwarded to a subsurface manifold 32 or is being taken from a common sump hole 8, the monitoring of the recovered fluid from the individual lower laterals may be accomplished before that fluid is intermingled with fluid from the other lower laterals. Use of the common sump hole 8 for recovering laterals is more fully described in my co-pending application Serial No. 334,159.

Referring again to Figure 2, the following is an example of the monitoring procedure described above. Steam may be initially injected into the four laterals 14, 15, 16 and 17, forming a substantially horizontal blanket of steam in the plane of the upper laterals. Continued injection of the steam will drive the oil in the formation to the lower laterals. Once steam or condensate has been recovered from one of the lower laterals, e.g., lateral 21, steam may be continued to be injected into the upper laterals 15 and 16, while steam is not injected into the upper laterals 14 and 17. Thus, oil recovery would continue from the lower laterals 18, 19 and 20, but oil recovery from the lower lateral 21 would be effectively discontinued.

An alternative procedure that may be used when steam or condensate is recovered in one of the plurality of lower laterals is to inject cold water into the lower lateral while continuing steam injection into the upper laterals. Referring to the example described immediately above, if water or condensate is being recovered from the lower lateral 21, cold water may be injected into lower lateral 21 while continuing to inject steam in either upper laterals 15 and 16 or all the upper laterals 14, 15, 16 and 17. The introduction of the cold water into the lower lateral 21 effectively terminates the recovery of any fluid from the lateral 21, thus the steam injected into the formation would be effectively used to produce oil from the laterals 18, 19 and 20.

One of the advantages of the plurality of upper laterals 14, 15, 16 and 17 is that a blanket can be easily and rapidly established in the formation which will enhance the driving efficiency of the injected fluid. The rapid establishment of a blanket in the formation will increase the thermal efficiency of the recovery process since less heat and injection fluid will be lost to adjacent beds or escape from the formation entirely. Conventional vertical injection wells do not result in the rapid and efficient establishment of a blanket, since the fluid is injected at points within the plane of the blanket. According to the present invention, the laterals lie within the plane of the blanket to be established, and thus lines of injection are provided rather than mere points of injection. The particular number of laterals used will depend on a variety of factors. It is within the concept of the present invention that a pluralilty of laterals radiate from the mine shaft at at least two vertical elevations. The embodiment illustrated in Figure 2 shows four upper laterals and four lower laterals, but any number of upper and lower laterals may be used. For instance, eight equally spaced upper laterals could be used in conjunction with eight equally spaced lower laterals. The efficiency of the recovery process would be generally enhanced by the increased number of laterals, but the increased number of laterals also results in increased drilling and equipment costs.

It is preferable that equal numbers of upper laterals and lower laterals be provided, and that the individual upper laterals and individual lower laterals be equally spaced from each other. Thus, as shown in Figure 2, each of the upper laterals is 90° apart from adjacent upper laterals, and the lower laterals are 90° apart from adjacent lower laterals. In addition, it is preferable that lower laterals be spaced between upper laterals, as compared to having the lower laterals directly below the upper laterals. As shown in Figure 2, each of the lower laterals is 45° apart in the horizontal direction from its adjacent upper laterals; if eight upper laterals were used in conjunction with eight lower laterals, each lower lateral would preferably be offset from its adjacent upper lateral by 22.5°. One advantage in offsetting the lower laterals from the upper laterals is that a longer path is thereby provided between the injection laterals and the recovery laterals. Thus, the injection fluid tends to spread out evenly through the formation and increase the sweep efficiency of the recovery process. If the upper laterals were to be placed directly above the lower laterals, there is less likelihood that the oil near the bottom of the formation and between the lower laterals would be recovered.

As previously described, the use of upper and lower laterals within a formation enables a blanket to be easily formed for the driving process. It is possible to use conventional vertical injection wells instead of the injection laterals, although the blanket of driving fluid may not be established as readily as if horizontal boreholes or laterals were used for the injectors. Referring to Figure 5, there is illustrated another form of my invention which employs the use of conventional vertical wells 60 and 62. It will be seen that these conventional vertical wells 60 and 62 are drilled from the surface 64 through the top rock layer 66 and terminate in the upper portion of the formation 68. Fluid may be injected into the vertical wells from a common generator, or separate generators 70 and 74 may be employed for each vertical well. Valves 72 and 73 may be used to control the flow of fluid from the generators to the formation.

The laterals 76 and 78 extend radially from the work chamber 80 in the lower portion of the mine shaft 82. The lower set of laterals preferably "blanket" a portion of the formation, as previously described. Valves 83, 84 and 86 may be used to control the recovery of oil from the laterals to the recovery tank 88. In Figure 5, both the laterals 76 and 78, and the work chamber 80 are entirely within the lower portion of the formation 88, and lie above the rock layer 90.

It is also within the concept of my invention to utilize conventional vertical boreholes in combination with both upper and lower laterals, if desired, to assist the formation of a blanket and the driving process. Thus, in Figure 5 there is illustrated vertical injection wells 60 and 62 plus horizontal laterals 92 and 94. By controlling valves 96, 98 and 100, the injection of fluid from the generator 70 to each of the horizontal injection laterals 92 and 94 may be controlled.

Referring now to Figure 6, there is shown a cross-sectional view of a portion of the apparatus depicted in Figure 5. The vertical injection wells are designed as 102, 103, 104, 105, 106, 107, 108 and 109, with wells 103 and 108 corresponding to the wells 60 and 62 shown in Figure 5. The horizontal recovery laterals form a generally rectangular blanket, and are designated as laterals 112, 113, 114, 115, 116, 117, 118 and 119, with laterals 113 and 117 corresponding to laterals 76 and 78 in Figure 5.

It will be seen that the vertical wells may be spaced between the horizontal laterals, and that the injection wells are spaced geographically to cover the area to be blanketed. If desired, other injection wells may be spaced inwardly to the vertical mine shaft from the injection wells shown in Figure 6.

If horizontal injection laterals are utilized, it is anticipated that vertical injection wells would generally not be necessary. On the other hand, if vertical injection wells are utilized, it generally may not be necessary to drill horizontal injection laterals. However, it is possible to use both vertical and horizontal injections, and this may be desirable if only a relatively few number of injection laterals are utilized.

To assist in establishing a horizontal blanket if vertical injectors are used in combination with recovery laterals, fluid may be initially injected into a portion of the vertical boreholes while oil is recovered from the remaining vertical boreholes. Thus, fluid may initially be inserted into the odd-numbered vertical wells, and the oil may be driven horizontally and recovered by the adjacent even-numbered vertical boreholes until the injection fluid is recovered in the adjacent even-numbered vertical boreholes. At this point, a horizontal blanket of injection fluid is established, and fluid may be injected in all the vertical boreholes 102 through 109 to drive the oil downward for recovery by the lower laterals 112 through 119. In this embodiment, the vertical boreholes are preferably spaced between the injection laterals and toward the periphery of the blanketed zone to increase the efficiency of the recovery operation. As previously described, it is within the concept of this invention to drive vertically upward or vertically downward, and the conventional vertical boreholes herein described may terminate near the top of the formation if downward drive is desired, or may terminate near the bottom of the formation if upward drive is desired.

It is within the concept of this invention to employ a plurality of substantially horizontal laterals and inject fluid to drive the oil in the formation vertically toward recovery laterals. Oil may be driven vertically upward or downward, and thus the upper laterals and lower laterals may function either as injection laterals or recovery laterals. For instance, steam may be effectively used in many operations wherein the steam is injected into the upper laterals, since both the steam and the condensate at the temperature and pressure within the formation may be less dense than the oil. However, some miscible fluids which are more dense than the oil in the formation can also be effectively used as a driving fluid. If the injected fluid chosen, e.g., carbon disulfide, is more dense than the oil, it may be advantageous to inject the fluid in the lower laterals 18, 19, 20 and 21 while recovering oil from the upper laterals 14, 15, 16 and 17. In this case, the heavier injected fluid would easily and rapidly form a blanket in the lower portion of a formation, and continued injection would drive the oil upward toward the recovery laterals. Also neither gravity override or viscous fingering is a problem in this case during the driving operation, since the heavier injected fluid is below the oil to be displaced.

It may therefore be seen that the present invention is applicable with both miscible and immiscible injection fluids. Also, it is within the concept of my invention to inject a liquid lighter than the oil in a formation into the upper laterals, and thereafter to drive the oil downward toward the lower laterals by injecting a gas or a gas/liquid mixture in the upper laterals as the driving force. More particularly, a solvent less dense than the oil may be injected into the upper laterals to form a blanket of fluid to act as the face of the driving force. Successively lighter slugs of fluid, each slug having a lower density than the previous slug, may thereafter be injected into the formation. Finally, a gas may be injected. The injection slugs of fluid and gas produce a driving force, and the solvent first injected acts as the face of the driving force. This technique, which may be referred to as graded miscible displacement, may be highly effective, permit much higher injection rates, and yield higher production rates than possible according to the prior art.

The density of the injection fluid may vary with temperature changes to a different extent than the oil in the formation. It is possible, therefore, to inject a particular fluid in the top laterals as a driving force when that fluid is lighter than the oil, and to inject the same fluid in the lower laterals as a driving force when the fluid is heavier than the oil in the formation. Referring now to Figure 4, there is depicted a chart which illustrates the approximate density of the water, 10° API oil, 12° API oil, and 14° API oil as a function of temperature. It will be noted that at 100° F., water is denser than 12° API oil, but that at 500° F., 12° API oil is denser than water.

The principle of different density changes for fluids can be fully utilized according to the present invention. For example, high temperature steam can be injected into the upper laterals, and 12° API oil can be recovered by the lower laterals. At the pressure within the formation, the condensate from the high temperature steam may form a layer of water at 300° F. In this case, both the steam and the condensate are lighter than the oil, and can be efficiently used to drive the oil downward. After steam or condensate has been recovered from one of the lower laterals, the injection of steam may be continued in the upper laterals that are not adjacent the lower lateral from which the condensate was recovered, as previously described. (Alternatively, steam may be injected in all the upper laterals while cold water is injected in the lower lateral from which condensate or steam has been recovered). If the formation were at a relatively shallow depth and therefore correspondingly lower formation pressures existed, it is within the concept of my invention to inject superheated steam to achieve the high temperature desired to maximize the efficiency of the recovery process.

After the downward steam drive has been completed, the driving process may be reversed and cold water may be injected in the lower laterals while oil is recovered from the upper laterals. From the graph in Figure 4, it may be seen that at a temperature of 100° F., water is more dense than 12° API oil, and thus the injection of water will now drive some of the remaining oil in the formation upward toward the upper laterals. Thus, during both the vertically upward driving stage and the vertically downward driving stage, the density of the injected fluid enables an effective blanket to be established, and the likelihood of viscous fingering is substantially eliminated.

Although driving vertically in one direction according to the present invention will effectively sweep the formation, it is understood that the oil recovery process will not be 100% effective. Driving in both directions, i.e., driving downward and thereafter driving upward, will increase the percent of oil recovered. This increased recovery is due, in part, to the fact that formations are not completely homogeneous, and thus driving in the reverse direction will cause the driving fluid to invade some areas that may have been sheltered from the forward driving fluid. Also, the injection of cold water in the lower laterals, as described above, may cause some water to flash to steam because of the residual heat in the formation, and the steam may lower the viscosity of some remaining oil to enhance the effectiveness of the upward driving process.

In the methods described above, oil recovery is based on a vertical drive process, which may be simplicity described as injecting the fluid in one set of boreholes while recovering oil from another set of laterals. It is within the concept of my invention, however, to improve the efficiency of the vertical driving process by providing for a limited soak cycle for each of the sets of laterals. For instance, if a vertical downward drive of the oil is to be achieved, it may be initially desirable to inject steam in the lower laterals to soak the formation directly adjacent the lower laterals and thus improve the subsequent driving process. Also, the upper laterals may be thereafter injected with steam to soak the formation adjacent the upper laterals and therefore enhance the uniformity of the driving blanket. After the lower laterals have been opened and oil begins to flow in the lower laterals, steam may thereafter be injected in the upper laterals to drive the oil toward the lower laterals.

Soaking the formation about the upper and lower laterals prior to establishing the driving process, as described above, may be beneficial in most applications. If a high viscosity oil is to be efficiently driven, it may be desirable, if not essential, to establish a flow path between the point of injection and the point of recovery prior to the driving cycle. The heavy oil in many formations has such a high viscosity that it is very difficult to displace the oil by an injection fluid supplied from commercial generators.

If steam is to be used as the injection fluid in the application depicted in Figure 1, the efficiency of the downward driving process may be substantially increased by first injecting steam in the lower set of laterals 18, 19, 20 and 21. As the lower portion of the formation 6 is being soaked, viscous fingering and gravity override will readily occur since the injected fluid is lighter than the oil, and is being introduced in the lower portion of the formation. As viscous fingering and gravity override occur, heated communication paths will be established between the lower set of laterals and the upper set of laterals. Thus, the formation may be subjected to repeated steam soak cycles from steam supplied through the lower set of laterals, wherein steam is injected into the lower laterals, the laterals are stopped off or shut in, and the laterals are opened for recovery of oil as a result of the soaking process.

When the repeated soaking from the lower laterals results in steam fingering to the top of the formation 6, the soaking process may be discontinued and steam thereafter injected into the upper set of laterals 14, 15, 16 and 17 for driving the oil downward while recovering oil from the lower set of laterals. The steam soak cycle therefore results in communication paths between the injection locations and the production locations which may have a greater area than that commonly associated with horizontal driving techniques. For instance, when conventional horizontal drive between vertical wells is utilized in a formation 60 feet thick, the area of face of the driving formation is typically approximately 12,500 square feet per acre. If vertical drive is practiced between horizontal laterals according to the present invention, the area or face of the driving front increases to approximately 43,000 square feet per acre. Thus, if the same injection rate per area of driving front is utilized, fluid is injected at approximately 3.5 times the rate as in conventional horizontal drive. Moreover, since the oil is being driven vertically rather than horizontally, the injection rate per area of the driving front may be substantially increased since viscous fingering is substantially eliminated during the driving operation.

The larger driving face area, therefore, enables more driving fluid to be injected into the formation while maintaining a relatively low, stable driving velocity across the formation. Also, as previously mentioned, the driving velocity may be substantially increased when compared to horizontal drive since vertical driving minimizes the likelihood of viscous fingering. Further, the fluid may be injected at higher pressures and at higher rates than realized in the prior art, which improves the efficiency of the recovery process. For instance, steam which may have been injected at 25% quality in horizontal drive operations may effectively be injected at the higher rates and with greater steam quality, e.g., 80%, than in the prior art. Also, as previously mentioned, superheated steam may be used as the injection fluid.

Although this invention has principally been described with steam or water as the injection fluid, both heated and unheated fluid may be used as a driving force within the concept of my invention. For example, water, solvents, gas, oil, distillate, LPG, and naptha, or a combination of liquids and gases may be utilized as the driving fluid according to the present invention. Examples of gases that may be used in this invention are air, oxygen, hydrogen, carbon dioxide, inert gas, stack gas, steam, anhydrous ammonia, natural gas, ethane, propane and butane. Also, although no additives must be combined with the fluid to be injected, the addition of additives may enhance the recovery process. Less heat is lost through condensation, and the average temperature of the formation is raised at a faster rate than in the prior art. Thus, the increased injection rates yield higher production rates, which improve the economics of the recovery operation.

It is also within the concept of this invention to utilize in situ combustion to achieve or enhance vertical drive of the oil toward horizontal recovery laterals. For instance, if horizontal laterals are placed near the bottom of the formation, in situ combustion near the top of the formation will tend to drive the oil downward. Air or oxygen for the combustion process may be injected via either conventional vertical injection wells from the surface to the upper portion of the formation or horizontal laterals from the mine shaft. Referring to Figures 5 and 6, if desired air or oxygen may be injected via the odd-numbered vertical wells, and in situ combustion used to recover oil from the even-numbered vertical wells as the combustion process drives the oil in the upper portion of the formation horizontally. After in situ combustion has progressed in a horizontal direction and the producing even-numbered vertical wells become heated, all the conventional vertical wells 102 through 109 may be used to inject air or oxygen. Thus, in situ combustion may thereafter be utilized to drive the oil downward for recovery by the laterals or boreholes 112 through 119. If desired, this latter operation may be conducted in rotating segments, rather than exploiting the entire area at one time, which would reduce the capital investment required for the air or oxygen compressors.

Alternatively, in situ combustion may be conducted in the upper portion of the formation between conventional vertical wells, as previously described, and thereafter another fluid such as water, steam, inert gas or mixtures thereof injected into all the vertical wells for driving the oil downward for recovery by the horizontal laterals. If desired, the lower horizontal laterals may be initially steam soaked or soaked at intervals during the driving process to maintain the desired recovery flow. The in situ combustion between the conventional vertical wells may be conducted until enough heat has been added to the formation for an efficient oil recovery by subsequent vertical drive techniques. If water is injected into the formation as the driving fluid from the vertical conventional wells, the residual heat from the "burned out" zones may generate steam in situ which may efficiently drive the remaining oil downward for recovery by the laterals.

The above operation is especially attractive from an economic standpoint since little or no surface fuel is used to heat the formation. Temperatures in the combustion zone may be 800° F. to 1000° F. or more, and very good drive of heavy oil can be achieved if the oil in the formation is heated to 250° to 300° F. Also, creating a blanket of combustion-cleaned matrix establishes extremely high vertical downward transmissibility for the injected fluids used in the subsequent driving cycle. In situ combustion further dehydrates and breaks down any shale layers or lenses within the combustion zone.

The recovery of oil when utilizing vertical drive, as described according to my invention, may be further enhanced by reducing the pressure at the recovery laterals to a sub-atmospheric value by connecting the recovery laterals to suction-type pumps. In this manner, oil recovery may be enhanced regardless of whether the vertical drive is propagated by in situ combustion, steam injection, solvent injection, gas injection, or injection of any number of fluids commonly used to enhance the driving operation.

The injection laterals in the embodiments described are preferably positioned in a substantially horizontal plane. The laterals may be inclined to conform to the inclination of the barrier layer, but the injection laterals with the injected fluid principally serve to establish a uniform, substantially horizontal blanket to be driven vertically through the formation. The recovery laterals are generally positioned in a similar substantially horizontal plane so that the formation may be efficiently swept of oil. Some deviation of the laterals is expected, and in that sense the upper and lower laterals may not lie precisely in flat planes. Further, the laterals typically lie in relatively thin discs approximately five feet thick, and these discs or "planes" may be inclined slightly to conform to the barrier layers.

It may also be seen that the present invention may be profitably employed by installing a plurality of vertical mine shafts and laterals, as described herein. Also, by operating such multiple installations in a simultaneous manner, as more fully described in my co-pending patent application, Serial No. 334,159, an entire field may be drained in a systematic manner.

It may be that two or more oil bearing formations exist at different elevations. In such a case, it is within the concept of my invention that a vertical mine shaft may be employed, and upper and lower laterals may extend from the mine shaft into each of the oil bearing formations.

As hereinbefore described, the techniques of the present invention are principally directed to recovery of relatively heavy oils. However, it should be noted that these techniques are not limited to heavy oils only, but can be used with substantial affect in recovering hydrocarbons of various weights and gravities.

Other alternate forms of the present invention will suggest themselves from a consideration of the apparatus and practices hereinbefore discussed. Accordingly, it should be clearly understood that the systems and techniques depicted in the accompanying drawings, and described in the foregoing explanation, are intended as exemplary embodiments of my invention, and not as limitations thereto.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of recovering oil and the like from a subsurface earth formation, comprising the steps of:

establishing a shaft hole extending from the subsurface of the earth to said subsurface formation;

drilling a plurality of boreholes substantially laterally from the shaft hole into said subsurface earth formation;

drilling a second plurality of boreholes, all terminated substantially at another second level;

injecting into said formation through said second plurality of boreholes a displacing fluid to establish a substantially horizontal stratum of said displacing fluid;

injecting into said formation through said second plurality of boreholes a driving fluid under pressure to vertically drive said stratum of said displacing fluid through said formation; and

withdrawing oil from said shaft hole through said first plurality of boreholes while simultaneously injecting said driving fluid into said formation.

2. The method described in claim 1, wherein said step of drilling said second plurality of boreholes includes drilling a plurality of boreholes from the surface of the earth to the portion of the formation above said first plurality of boreholes and making outlet holes from said second plurality of boreholes at a level above said first plurality of boreholes.

3. The method described in claim 2, wherein said displacing fluid comprises substantially steam while said fluid under pressure comprised substantially a non-condensible gas.

4. The method described in claim 2, further including the steps of:

monitoring recovery of said driving fluid from each one of said first plurality of boreholes; and

injecting a fluid comprised substantially of water through selected ones of said first plurality of boreholes in accordance with withdrawal of said driving fluid from each one of said first plurality of boreholes in order to prevent further withdrawal of said driving fluid.

5. The method described in claim 2 wherein another driving fluid is injected through said first plurality of boreholes into the formation in order to vertically drive the oil towards said second plurality of boreholes; and

withdrawal of oil from said second plurality of boreholes while simultaneously injecting said second driving fluid into said formation.

6. The method described in claim 2 further including the steps of:

injecting the soaking fluid through said first plurality of boreholes into said formation until said fluid reaches at least one of the second plurality of boreholes;

thereafter injecting said driving fluid through said second plurality of boreholes into said formation;

establishing at least 100 psi (7 kg/cm^2) pressure difference between said first and second pluralities of borehole by injecting said driving fluid; and

maintaining such pressure difference during driving the oil towards said first plurality of boreholes.

7. The method described in claim 1 wherein the step of drilling the second plurality of boreholes includes drilling said second plurality of boreholes from the surface of the earth into the portion of said formation located below said first plurality of boreholes where said second plurality of boreholes are terminated at substantially the same level.

8. The method described in claim 7 further including:

monitoring the recovery of said driving fluid from each one of said first plurality of boreholes; and

injecting a fluid comprising substantially water through selected ones of said first plurality of boreholes depending upon the withdrawal of said driving fluid from each one of said first plurality of boreholes in order to prevent further withdrawal of said driving fluid.

9. The method described in claim 7 further including the steps of:

thereafter injecting another driving fluid into said formation through said first plurality of boreholes in order to vertically drive the oil towards said second plurality of boreholes; and

recovering oil from said second plurality of boreholes while simultaneously injecting into said formation said second driving fluid.

10. The method described in claim 1, wherein the step of drilling said second plurality of boreholes includes drilling another plurality of boreholes radially from said shaft hole at another level, different from that of said first plurality of boreholes.

11. The method described in claim 10, wherein said displacing fluid is comprised substantially of steam whereas said driving fluid is comprising substantially a non-condensible gas.

12. The method described in claim 10, further including the steps of:

thereafter injecting another driving fluid into said formation through said second plurality of boreholes in order to vertically drive the oil towards said first plurality of boreholes; and

recovering oil from said first plurality of boreholes while simultaneously injecting said driving fluid into said formation.

13. The method described in claim 12, further including the steps of:

measuring oil production from each one of said second plurality of boreholes; and

controlling the injection of said driving fluid through selected ones of said first plurality of boreholes depending upon production of oil form each one of said second plurality of boreholes.

14. The method described in claim 10, wherein the step of injecting said driving fluid also includes:

establishing at least 100 psi ($7kg/cm^2$) pressure differerence between said first and second pluralities of boreholes by injecting said driving fluid; and

vertical driving of oil towards said second plurality boreholes.

15. The method described in claim 10, further including the setps of:

injecting said soaking fluid into said formation through said second plurality of boreholes until said soaking fluid reaches at least one of said first plurality of boreholes; and

injecting said soaking fluid which precedes the injection of said driving fluid into said formation.

16. Apparatus for recovering oil from a subsurface earth formation, comprising:

a shaft extending from the surface of the earth to said subsurface earth formation;

a first plurality of boreholes extending radially from said shaft and lying within a substantially horizontal first plane within said formation at a first elevation;

a second plurality of boreholes all terminated substantially at another second level and comprising fluid output means for defining a layer of fluid;

injection means introducing a displacing fluid through said second plurality of boreholes to provide a layer of displacing fluid;

pressurizing means introducing a driving fluid through said second plurality of boreholes for driving the layer of displacing fluid vertically toward said first plurality of boreholes; and

recovery means for withdrawing oil from said first plurality of boreholes.

17. Apparatus as defined in claim 16, wherein said first plurality of boreholes lies in a substantially horizontal first plane in a lower portion of said formation, each of said second plurality of boreholes extends from said surface of the earth and terminates at said second elevation in an upper portion of said formation, and said injection means comprises means for injecting a displacing fluid less dense than said oil.

18. Apparatus as defined in claim 16, wherein said first plurality of boreholes lies in a substantially horizontal first plane in an upper portion of said formation, each of said second plurality of boreholes extends from said surface of the earth and terminates at said second elevation in a lower portion of said formation, and said injection means comprises means for injecting a displacing fluid more dense than said oil.

19. Apparatus as defined in claim 16, wherein each of said second plurality of boreholes extends radially from said shaft.

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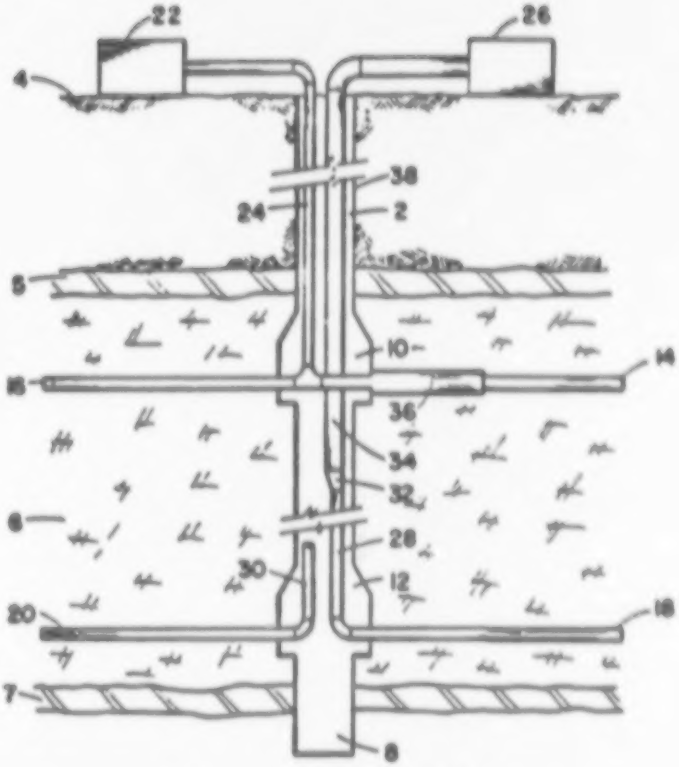
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FIG. 1

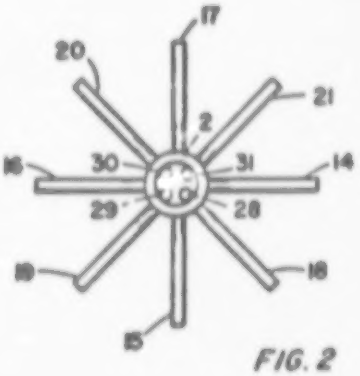
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FIG. 2

INVENTOR
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PATENT AGENTS

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2-3

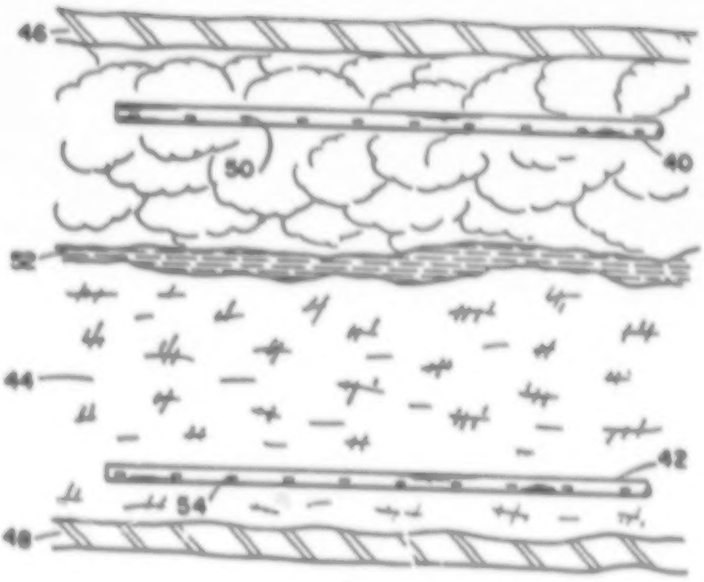
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FIG. 3

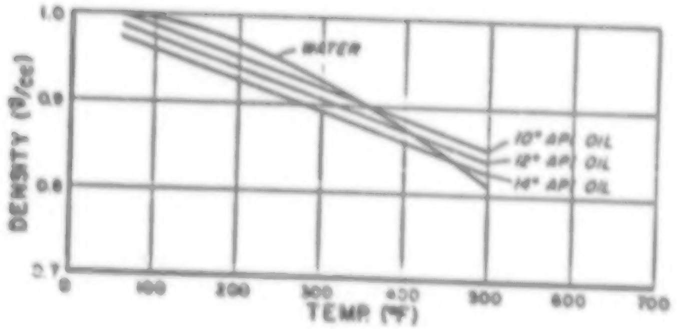

FIG. 4

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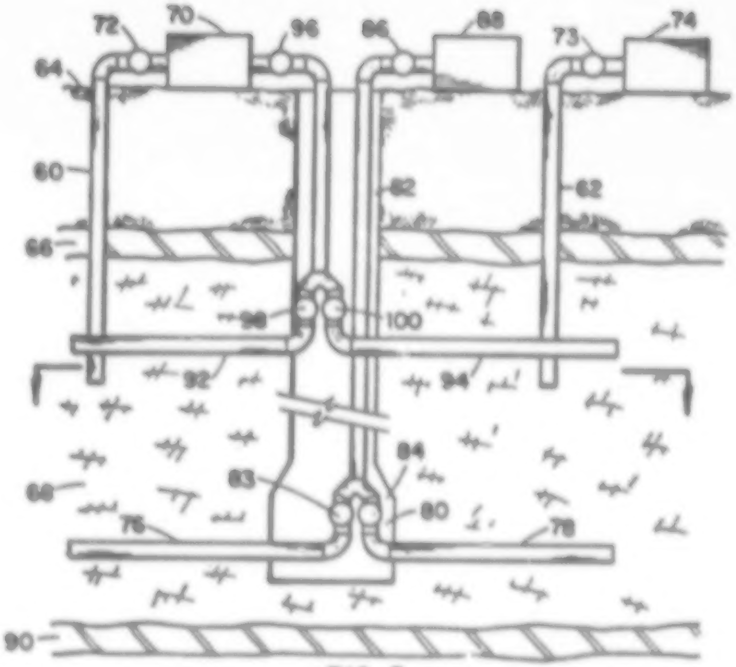
1148854
3-3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100
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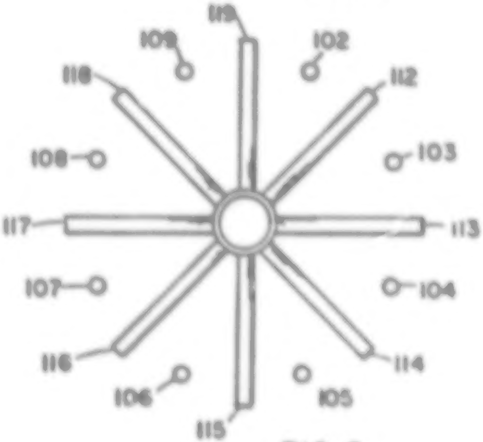
FIG. 5


119
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102
118
112
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103
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113
107
104
116
114
106
105
115

FIG. 6

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PATENT AGENTS

309391

Alberta OIL SANDS INFORMATION CENTRE

United States Patent [19]
Willman

[11] **4,390,067**
[45] **Jun. 28, 1983**

[54] METHOD OF TREATING RESERVOIRS CONTAINING VERY VISCOUS CRUDE OIL OR BITUMEN

[75] Inventor: **Bertram T. Willman**, Calgary, Canada

[73] Assignee: **Exxon Production Research Co.**, Houston, Tex.

[21] Appl. No.: **251,587**

[22] Filed: **Apr. 6, 1981**

[51] Int. Cl.³ **E21B 43/24**
[52] U.S. Cl. **166/245**; 166/50; 166/272
[58] Field of Search 166/50, 272, 252, 245, 166/271, 273, 274, 263

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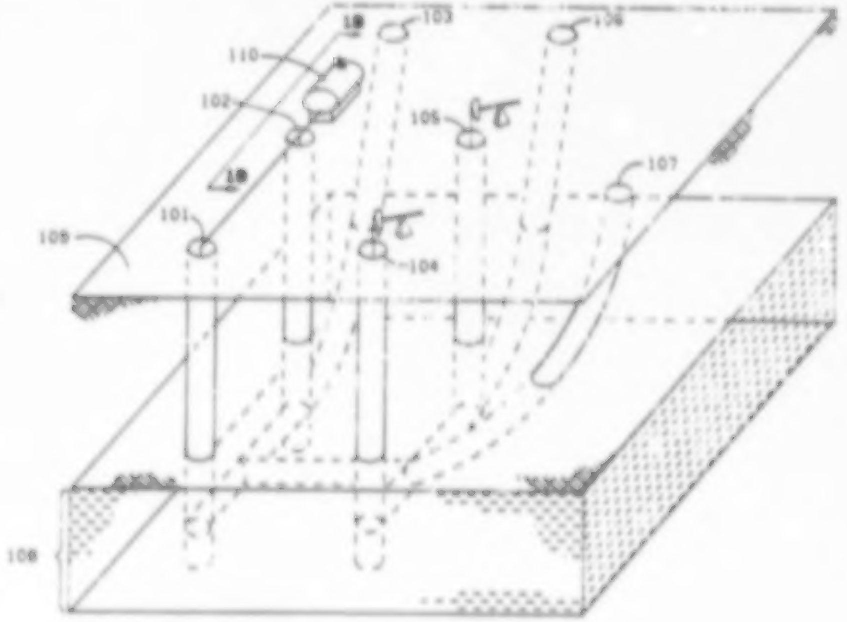
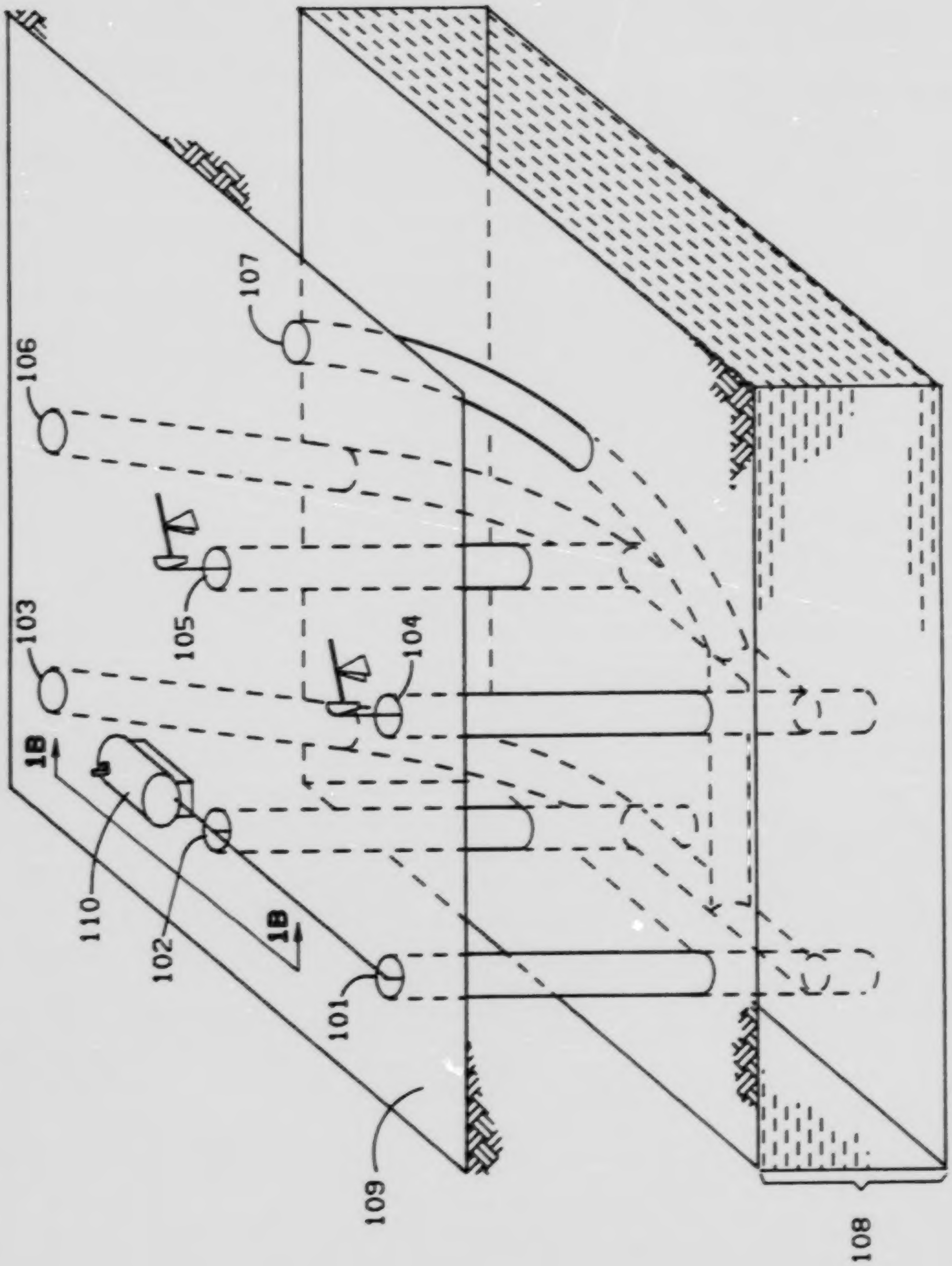
Primary Examiner—Stephen J. Novosad
Attorney, Agent, or Firm—E. T. Wheelock

[57] ABSTRACT

A method for treating a field containing viscous oil or bitumen for subsequent production is described. The steps central to the process are drilling a horizontal well within the oil-bearing stratum, and heating the oil in the vicinity of the horizontal well to produce a hot liquid corridor. The open borehole is filled and the oil in the heated corridor is displaced from one end to the other. The corridors may be connected in various configurations to effectively displace a high percentage of oil in a particular field.

21 Claims, 11 Drawing Figures




101
102
103
104
105
106
107
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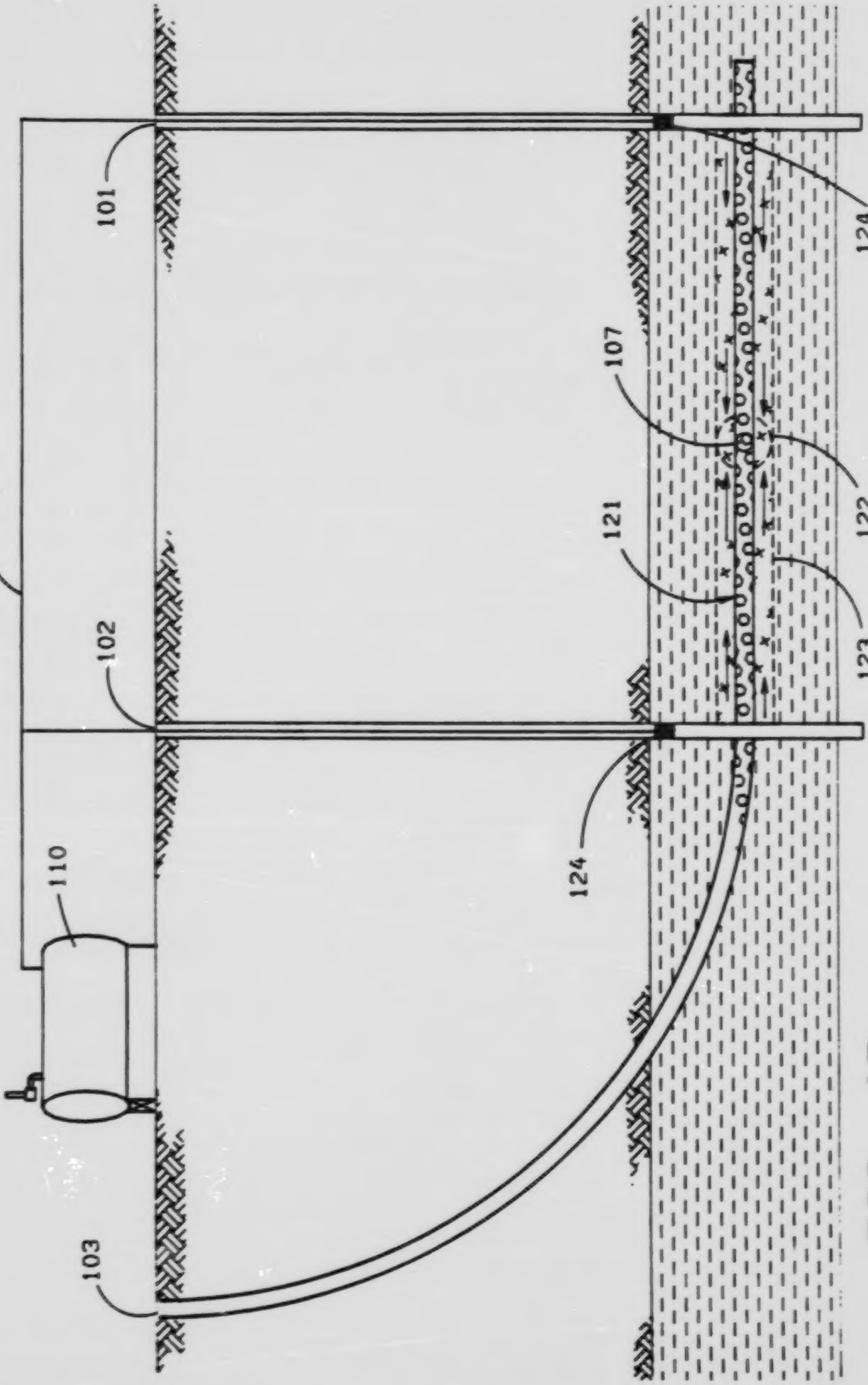
109
110
1B
1B

FIG. 1A


101
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121
122
123
124
124

FIG. 1B

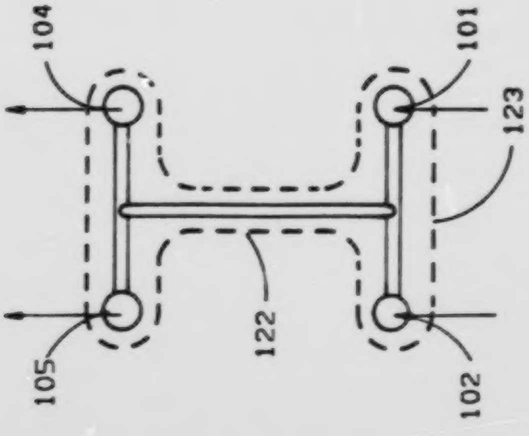


FIG. 2A
104
101
123
122
105
102

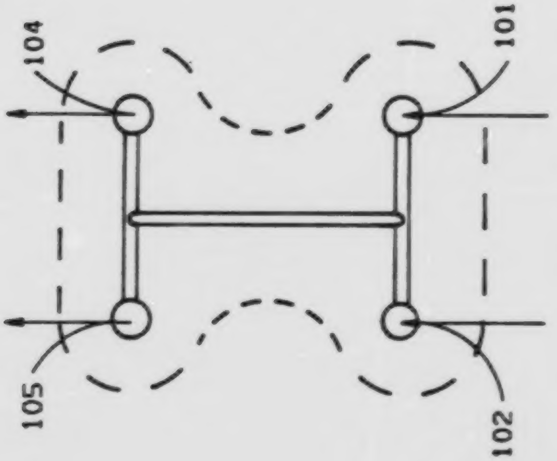


FIG. 2B
104
101
105
102

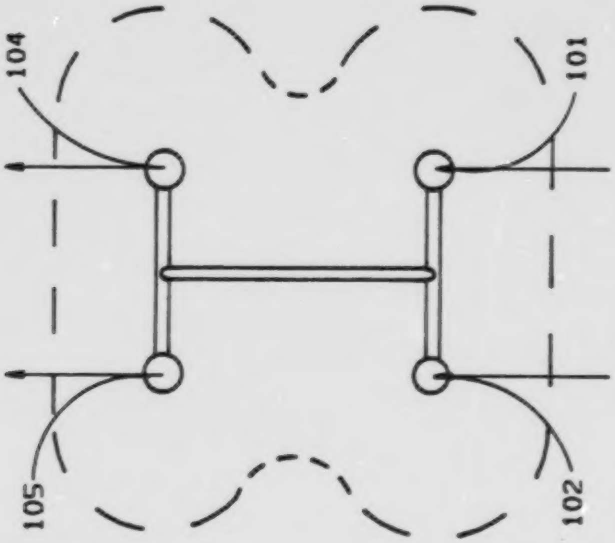


FIG. 2C
104
101
105
102

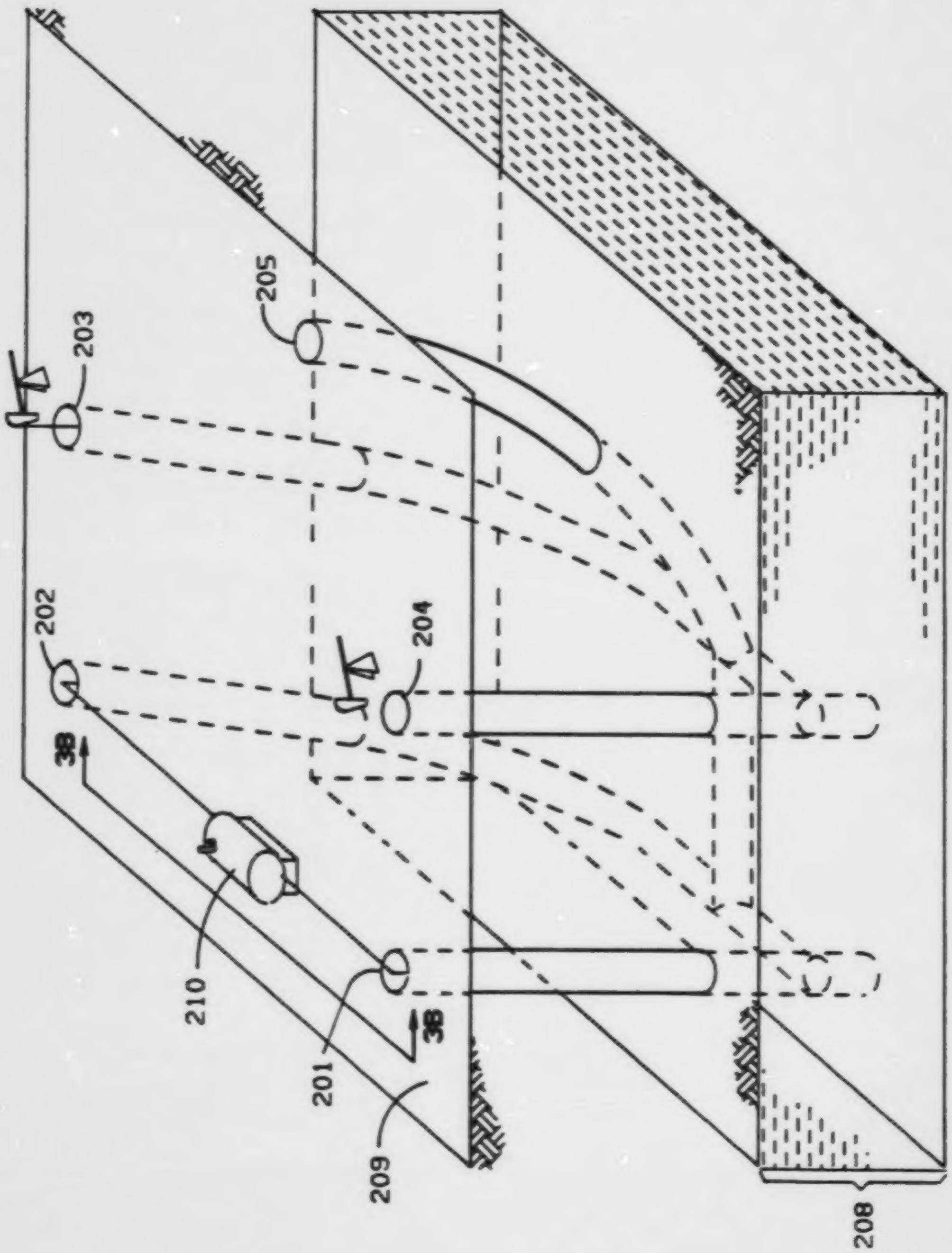

205
203
202
204
3B
210
201
3B
209
208

FIG. 3A

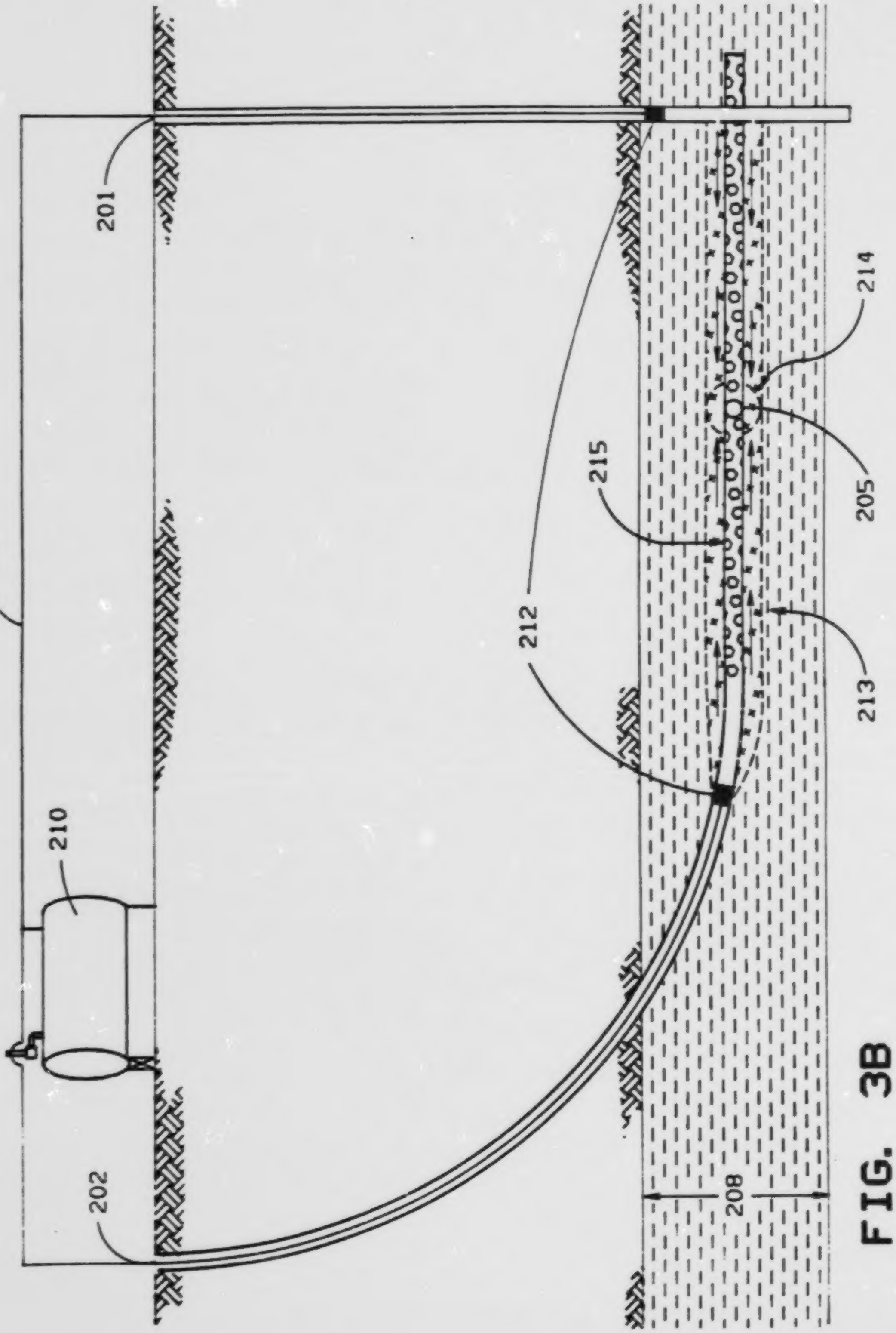

201
202
205
208
210
211
212
213
214
215

FIG. 3B

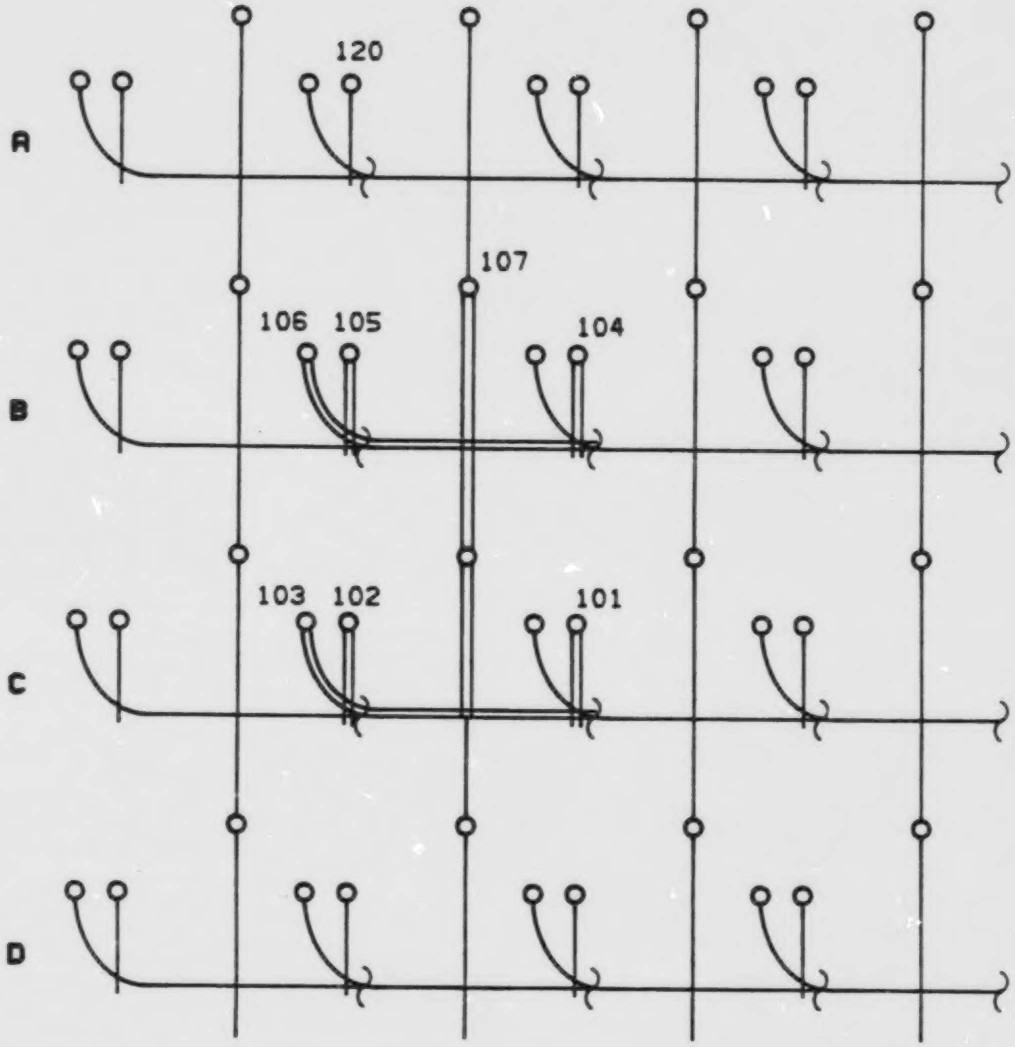
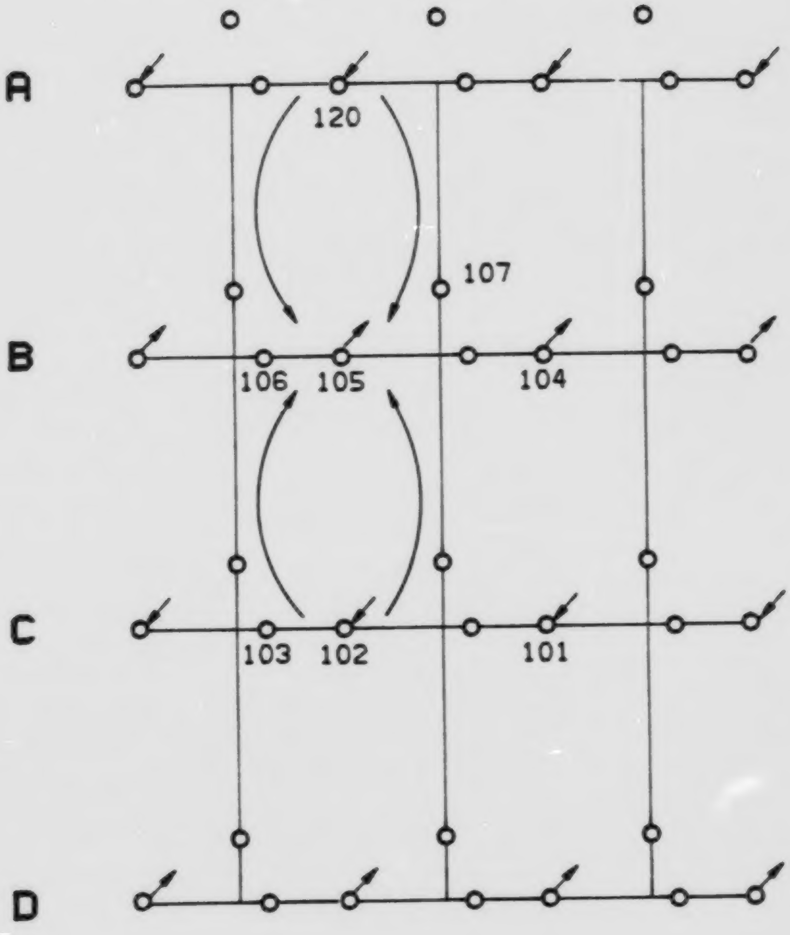

120
A
107
106
105
104
B
103
102
101
C
D

FIG. 4A


A
B
C
D
120
107
106
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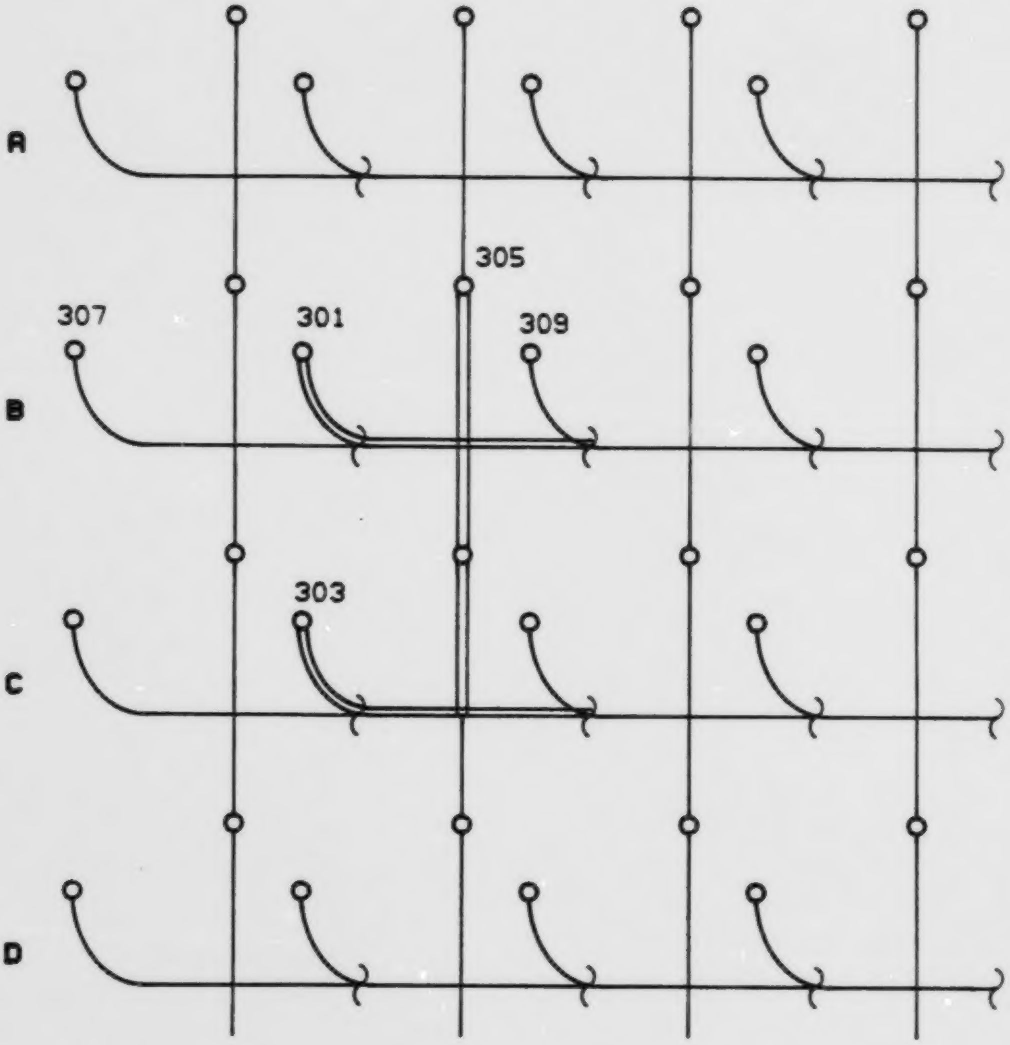
104
103
102
101

FIG. 4B


A
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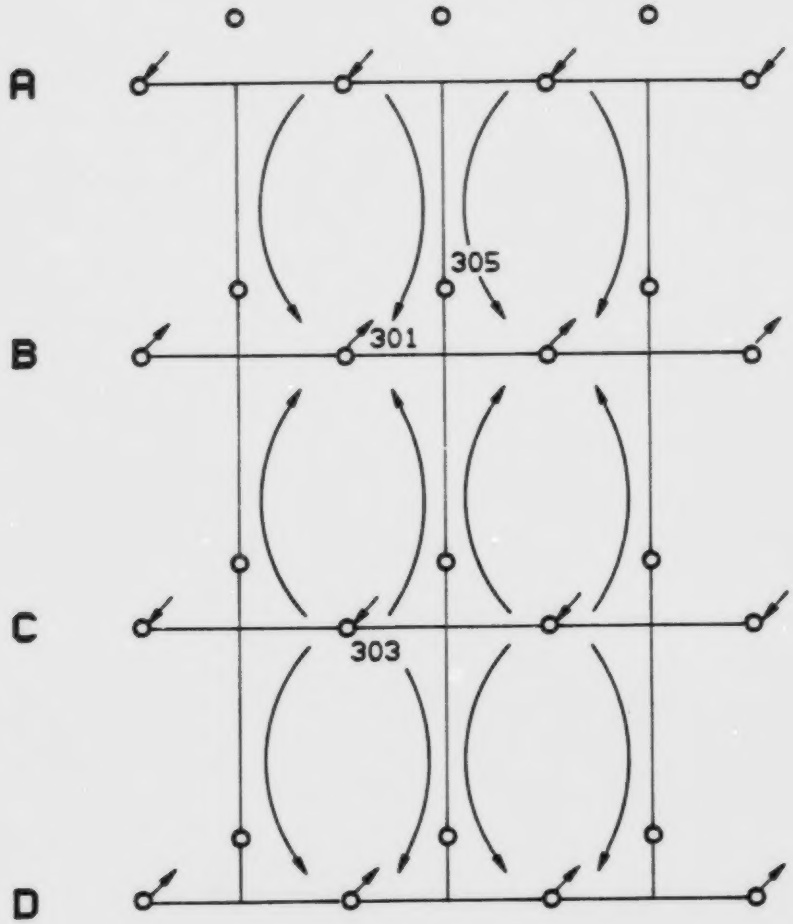
307
301
309
B
303
C
D

FIG. 5A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D
305
301
303

FIG. 5B

METHOD OF TREATING RESERVOIRS CONTAINING VERY VISCOUS CRUDE OIL OR BITUMEN

BACKGROUND OF THE INVENTION

This invention relates to a novel method of treating subsurface deposits containing heavy or viscous oil so that it may be recovered using hot fluid displacement techniques.

There exist throughout the world major deposits of heavy oils which, until recently, had been substantially ignored as sources of petroleum since the oils contained therein were not recoverable using ordinary production techniques. For instance, only lately has much interest been shown in the heavy oil deposits of Alberta province in Canada even though the deposits are both close to the surface and represent an estimated petroleum resource upwards of many billion barrels. The expense involved in the production of these oils stems from the fact that they are quite viscous at reservoir temperatures. A viscosity of 10,000 centipoise to several million centipoise characterizes Athabasca crude oil. Unless the deposit is on the surface and the heavy-oil-containing material can be mined and placed in a retort for separation from its matrix, some method of treating the deposit in-situ need be utilized for the realization of any substantial petroleum recovery.

Interwell displacement has been recognized as the most efficient method of in-situ recovery of heavy oils. However, before displacement can commence, a warm and liquid communicating path must be established between wells since viscous oil will not flow at any commercial rate until its viscosity is reduced by heat. In-situ or reservoir heating to try to create this communicating path is generally done by steam stimulation, i.e., injection of steam at above fracturing pressure and subsequent production, on an individual well basis. This process does not result in a well defined heated volume. Since the steam is injected into the formation above fracture pressure, the steam takes the unpredictable path of least resistance in the often unconsolidated strata containing the viscous oils. Consequently, oil which would be recoverable by the present invention is not produced. For these reasons it is a formidable task to recover a substantial percentage of the heavy oil in a selected formation while efficiently utilizing available steam. This invention is intended to provide an effective manner for treating and recovering viscous oils.

A number of methods have been suggested for in-situ thermal recovery of viscous oil deposits.

One of the earliest methods entails the steps of first, drilling a single vertical borehole into the petroleum-bearing formation and then injecting a heated fluid such as steam or water into the formation thereby causing the hydrocarbon to become less viscous and flow. The thusly-heated hydrocarbon is finally pumped from the same vertical borehole. Obviously this method is slow, since there is no mean hydraulic force to continually urge the oil towards the wellbore and no source of heat to maintain it in a liquid, or at least pumpable, state. For these reasons, the proportion of petroleum that can be recovered from a particular formation is quite low.

Another early suggestion, in U.S. Pat. No. 3,349,845, to Holbert et al, provides a somewhat complicated method for recovering viscous oils from shale formations. The process entails first drilling a vertical injection well and thereafter forming a system of vertical fractures which, if desired, may be propped open with sand or other granular solids. A horizontal, or output well, is then drilled to intersect the vertical fracture system. A heated petroleum corridor is established by heating the injection well under a low gas pressure. The heating is continued until a zone at least 40 or 50 feet along the wall of the vertical injection well is created. Holbert et al suggests that the entire stratum between injection and output well can be heated but that is usually neither necessary nor desirable. The fractures are then plugged at the injection well. Plugging provides assurance that the subsequently added displacement fluid, which may be steam, displaces the oil into the output well rather than merely flowing through the fractures.

Holbert et al, although alleging the utility of its disclosed process with respect to tar sands, is apparently quite specific to oil shales and of only minor relevance to tar sands. For instance, vertical fracturing is a required step in the process, and yet U.S. Pat. No. 4,020,901, to Pisio et al, indicates that attempts to fracture tar sand formations in a controllable manner do not meet with success. Vertical fractures often terminate uselessly at the surface. The fractures often tend to "heal" as mobilized viscous petroleum flows through the cracks and cools to its immobile state. Pisio et al, additionally mentions that tar sands frequently underlie intermediate overburden layers which are easily fractured.

The Holbert et al process is not particularly useful at a viscous oil deposit such as that found at Athabasca. Much of the Athabasca tar sands are at a depth too deep to mine and much too shallow to create suitable fractures.

Holbert et al additionally suggests propping open the fractures with some known proppant such as sand. When the stratum under consideration is oil shale, propping is a step which facilitates oil flow. However, in the case of a tar sand which is composed of a viscous oil and sand, the use of sand as a proppant is somewhat akin to "carrying coals to Newcastle." The proppant supply becomes part of the sand matrix and the fracture closes.

Finally, it is generally accepted that fracturing an unconsolidated formation such as by tar sand gives unpredictable results, at least with regard to the orientation of the fracture. On the other hand, consolidated formations, such as the oil shales of Holbert et al, can be fractured with reasonably predictable results. The disclosure in Holbert et al requires knowledge of the fracture's orientation so that the horizontal output well can be drilled to intersect the fractures. Knowledge of fracture orientation is unconsolidated tar sands is not, as a rule, available.

A subsequent development is found in U.S. Pat. No. 3,386,508, to Bielstein et al. This process for recovering viscous crude oils involves sinking a large central well, having a bore diameter of 1 to 10 feet, into a subsurface formation containing oil. A number of injection wells are then slant-drilled to intersect the central well within the subsurface oil-bearing stratum. Steam is then introduced into the injection wells only at the upper end of the stratum. Displaced heated oil permeates the walls at the lower end of the injection wells and passes into the central well where it accumulates and is pumped to the surface.

Bielstein et al does not heat an open horizontal borehole and then plug it as is done in the process of the present invention.

An additional set of related developments is found in U.S. Pat. Nos. 3,994,340; 4,020,901; and 4,037,658, to Anderson et al, Pisio et al, and Anderson respectively. Each produces a heated horizontal corridor by the physical placement of long heat exchangers in the tar sand stratum. The three differ from each other principally in the design of their heat exchangers. Each of these specifications additionally discusses the production problems which are unique to tar sands including the difficulty, mentioned above, of creating and maintaining an effective fracture network. None of the three suggests the straightforward and simple method of treating the petroleum-bearing stratum disclosed herein.

Other methods of attaining corridors of heated viscous petroleum, from which the heated oil can be displaced, are known. For instance, U.S. Pat. Nos. 4,010,799 and 4,084,637, to Kern et al and Todd respectively, teach a process in which a number of vertical wells are drilled down into the oil-bearing stratum, electrodes are inserted into the wells, and a voltage imposed across the electrodes in adjacent wells. Although it is understood that a prototype well involving such a process has been drilled, it is apparent that complete control of a resulting heated chamber position is not readily possible. The electric current will take the path of least resistance irrespective of where the driller would place the chamber. This problem is especially pronounced in areas where oil-bearing formations lie in close vertical proximity to electrically-conductive aquifers.

SUMMARY OF THE INVENTION

This invention relates to a method of treating subsurface formations containing viscous oil, heavy oil, or bitumen so that those oils may be recovered in a reliable manner during a subsequent production operation. This invention, in its simplest form, calls for preparing the oil deposit by drilling a relatively horizontal borehole for a distance within the oil-bearing stratum, heating the length of the borehole with an appropriate fluid, filling the borehole with a substantially nonporous material, and thereby producing a zone or corridor containing heated oil which is subsequently recoverable by known displacement techniques.

Since the heated corridors produced by the inventive treatment process are so well-ordered, recovery techniques using a grid-like pattern of injection and production wells are possible. Effective use of such a pattern results in a high percentage of petroleum recovery.

The inventive process has the advantage of being usable in being thin and thick oil-bearing strata as well as in those which are adjacent to water-bearing layers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B show a seven-well configuration or seven spot repeated pattern, in cutaway perspective and vertical section respectively, useful for practicing the present invention.

FIGS. 2A-2C show the progression of the shape of an H-shaped heated zone or corridor configuration as oil is displaced.

FIGS. 3A and 3B show a five spot repeated pattern in cutaway perspective and vertical section, respectively, useful for practicing the present invention.

FIG. 4A shows a front semi-elevation of a field having a number of seven spot repeated patterns.

FIG. 4B shows an elevation of the field of FIG. 4A.

FIGS. 5A and 5B show, respectively, a semi-elevation and an elevation of a field using interconnected 3-spot patterns.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A central feature of the inventive process rests in the attainment of a heated oil corridor within the oil-bearing stratum by the steps of drilling a horizontal borehole which extends for a distance within the subject stratum, heating the borehole and oil in its environs, and effectively plugging the heated horizontal borehole. A displacement fluid, such as steam, may subsequently be injected at one end of the heated corridor and displaced oil produced at the other. Plugging the horizontal borehole provides assurance that the displacement fluid performs its desired function rather than running uselessly through an open horizontal borehole.

This invention is not limited to a single horizontal heated chamber having an injection well at one end and a producing well at the other. It is normally desirable to lay out a particular field so that various horizontal heated corridors intersect in a chosen manner within the oil-bearing stratum. In this way the associated injection and production wells can serve multiple duty. A single displacement fluid injection well is then able to inject fluid directly or indirectly into a number of heated corridors and a single production well similarly may service a number of corridors. A number of well patterns suitable for optimum utilization of the invention are disclosed below.

For the purposes of this disclosure, a repeating layout of injection and production wells as connected by horizontal heated corridors is known as a "pattern". The surface wells in such a "pattern" are known as "spots". Hence a "five spot pattern" is a layout of five surface wells interconnected in some manner by heated corridors in the oil-bearing stratum. An "array" will be a collection of "patterns" possibly interconnected and possibly not.

Several alternative well patterns are contemplated as suitable for attainment of the desired heated corridors and having a configuration of injection and production wells satisfactory for subsequent production. In dealing with a petroleum-bearing stratum extending over a large area, it may be necessary to make a determination, based on the economics of the field, whether to produce the field with a large number of wells arranged in an array of well patterns, each having injector and producer wells, or simply with a single large pattern. The well configurations disclosed herein are suitable for both single patterns and multiple pattern fields. The consideration of well spacings, i.e., whether to use a single large pattern or multiple small ones, is a normal one in developing any oil field whether using this invention or other more conventional techniques.

One particularly useful well pattern is schematically depicted, in cutaway shadow perspective, in FIG. 1A and in vertical cross-section, as viewed from the injection well end of the pattern, in FIG. 1B. The use in a particular field of well patterns, such as the one in FIGS. 1A and 1B, in an interconnected array is discussed in some detail in conjunction with FIG. 4.

The seven spot pattern shown in FIG. 1A is produced by drilling four approximately vertical wells 101, 102, 104, and 105 down from the surface 109 substantially into the oil-bearing stratum 108. The spacing of these wells, as mentioned above, is determined by the economics of recovery in the particular field. The economic considerations would include such diverse information as the thermal conductivity of the oil stratum, viscosity of the heated oil, thickness of the oil stratum, and the type of horizontal drilling equipment available. In any event, horizontal distances between wells can be up to 1,000 feet or more in an oil stratum of about 150 feet. Horizontal wells 103 and 106 are then drilled to intercept, respectively, vertical wells 101, 102 and 104, 105 within the oil strata. A third horizontal well 107 is drilled which intersects the horizontal legs of wells 103 and 106 approximately halfway between their respective vertical wells. Methods for drilling horizontal wells are well known in this art and one suitable method is discussed at some length in Holbert et al, supra. Although the vertical placement of the horizontal wellbores within the stratum is not particularly critical, it is highly desirable to place them in the approximate vertical center of the stratum. The oil in many Canadian fields has a formation temperature of 45°-55° F. By placing the horizontal boreholes in the center, less of the applied heat entering via the heating stream is lost to the surrounding non-productive strata. Consequently, the heated channel will be larger in diameter.

The term "intercept", in referring to boreholes in this specification, is intended to include not only those boreholes which actually interconnect, but also those which are or will be effectively connected by a heated channel. For instance, vertical well 101 "intercepts" horizontal well 103 if it passes through the region about horizontal borehole 103 that eventually becomes a heated channel.

The order in which the wells are drilled is not important. It is contemplated that in some instances the vertical wells may be drilled during the time the horizontal wells are undergoing heat treatment or even thereafter.

In any event, before heating the horizontal legs of wells 103, 106 and 107 to establish the heated corridors, the wells should be cased and perforated. A steam injector of tubing may be inserted to near the end of those wells. Steam may then be introduced into the well through the tubing and condensate removed up through the annulus. Less desirably, since more heat will be lost to unproductive upper strata, the steam may be injected in the annulus and condensate returned up the tubing.

Vertical wells 101, 102, 104, and 105 are cased and also perforated within the oil-bearing stratum. It may be necessary to heat the perforated portion of a vertical well to provide assurance that either the vertical well or the heated region around the vertical well intersects the heated corridor around the horizontal leg. For instance, it may be necessary to heat the portion of wells 101 or 102 within the oil-bearing layer illustrated in FIG. 1B. Drilling is an inexact science and consequently well 103 may miss wells 101 or 102. Heating wells 101 or 102 to create a continuous hot oil corridor therebetween allows wells 101 and 102 to be used as injector wells.

The heating step should be continued until an amount of heat approximately equal to that found in 50-100 barrels of steam per linear foot of horizontal wellbore has been introduced into the formation. The steam may be wet and desirably would have a high temperature and a pressure as high as is possible without reaching the fracturing pressure of the formation. A pulse test should be performed after the heating step is completed to assure the existence of a heated liquid corridor between wells 101 and 102 as well as between wells 104 and 105. Of course, if the pulse test fails to confirm the existence of liquid corridors between the pertinent wells, heating should be started again.

The horizontal borehole is then plugged along its entire length by filling with an effectively nonporous material such as cement or a mixture of clay and rock as, for instance, shown at 121 in FIG. 1B. FIG. 1B depicts the pattern shown in FIG. 1A after the step of heating has been completed and the horizontal portion of well 103 has been plugged with cement 121.

The extent of the now-mobile hot oil corridor is shown at 123 as is the end of the heated corridor 122 associated with intersecting horizontal well 107. Steam of other suitable displacement fluid is heated in a boiler 110 and injected through steam lines 120 and introduced to the heated corridor 123 behind thermal packing means 124 in both wells 101 and 102. Although the use of steam lines 120 and packer 124 is preferable in that the annular spaces surrounding steam lines 120 are fairly effective insulators, injection of a heated displacement fluid directly into the cased vertical wells is acceptable. The heat and hydraulic pressure supplied by the steam tends to displace the heated oil from the ends of chamber 123 down into heated chamber 122 (as shown by the arrows in FIG. 1A) and from there into the two recovery wells, 104 and 105, at the opposite end of heated chamber 122. Although steam is discussed as the displacement fluid throughout this specification, it should be understood that other displacement fluids including hydrocarbon and other solvents, micellar dispersions, and surfactants may be added as desired.

Wells 104 and 105 can, in the alternative, be used as injection wells and wells 101 and 102 used as producers.

FIGS. 2A-2C are overhead views of the heated corridors, 122 and 123, surrounding wells 101, 102, 104, and 105 as those corridors grow during the production step illustrated in FIGS. 1A and 1B. The H-shaped configuration of the corridors is particularly advantageous to use with the heating step disclosed herein because of the potential for exceptionally high recovery efficiency. As steam displacement of the viscous oil takes place, the hot liquid corridors, e.g., 122 and 123 in FIG. 2A, tend to increase in diameter, and the once-right-angle meeting between corridor 122 and the other corridors begins to smooth in the manner shown in FIG. 2B. Further displacement continues such trend, as shown in FIG. 2C.

A similar and more desirable well layout producing the H-shaped heated corridors is depicted in FIGS. 3A and 3B. This embodiment, which is especially suitable for a field requiring a single five-spot pattern, uses only two vertical wells, 201 and 204. Horizontal wells 202 and 203, similarly to wells 103 and 106 in FIG. 1A, come down from the surface and take a largely horizontal route through the oil-bearing stratum to intersect wells 201 and 204. Horizontal well 205 intersects both wells 202 and 203 at a predetermined site within the stratum. This embodiment is more desirable than that found in FIGS. 1A and 1B since fewer wells are drilled.

Casing, perforating, and heating the horizontal wellbore is undertaken in a manner similar to that discussed above with regard to the configuration of FIGS. 1A and 1B.

The major significant difference between these embodiments lies in the plugging of the horizontal portions of wells 202 and 203. Only the lower portion of the horizontal bore is filled, with cement or clay and rock, 215 in FIG. 3B, since the subsequent displacement step requires the displacement fluid to come in contact with the heated chamber 213. As in the previously discussed embodiment, the displacement steam is generated in a steam generator 210 and flows through steam line 211 into wells 201 and 202 where it is injected into heated chamber 213 through perforations in the well casings. Packers 212, maintain the steam in contact with the heated bed 213. The steam tends to displace the viscous oil therein towards heated corridor 214 which surrounds plugged horizontal wellbore 205, through corridor 214, and from there into production wells 202 and 203.

Other configurations of injector and producer wells would be apparent to one having skill in the art based on this disclosure and would include such variations as: a single injection well and a single production well coupled by a heated corridor produced by the inventive heating method; a T-shaped configuration having either two injection wells on the cross-bar and one production well on the base of the 'T' or alternatively two production wells on the ends of the cross-bar and one injection well on the base of the 'T', all connected by heated corridors produced by the method of the invention; or a square with wells at each corner and one in the center in which the corners are used either as producer or injection wells and the center, respectively, is used as an injection or producer well.

Similarly, as mentioned above, it may be desirable to repeat a pattern of injector and production wells so as to effectively deplete a particular field. FIG. 4A provides a semi-elevation of such arrangement using an array of the seven spot pattern depicted in FIGS. 1A and 1B. FIG. 4B provides an aerial elevation of the arrangement of FIG. 4A. Producer wells 104 and 105 are in Row B of FIG. 4B and injection wells 101 and 102 are in Row C. Each well in Rows A and C is an injector well and is in hot corridor communication (as schematicized in the straight lines in the drawing) with the injector wells adjacent to it. Each injector well is in hot corridor communication through the H-network to the producer wells of Rows B and D.

Such an arrangement provides a multitude of sources for heat and hydraulic pressure on the heated oil as it moves towards a production well. For instance, well 105 produces oil displaced by steam from both injector wells 102 and 120 via the paths shown on FIG. 4B.

FIGS. 5A and 5B illustrate what could be considered a three-spot pattern which must be used in an interlocking array. The pattern, as shown in FIG. 5A, consists of two relatively parallel horizontal boreholes, 301 and 303, which are interconnected within the oil-bearing stratum by a crossing third horizontal borehole 305 to form a grid-like array. The casing, perforating, heating and plugging steps are executed on these horizontal boreholes in a manner similar to the steps discussed above with respect to the five-spot and seven-spot patterns.

Other horizontal wells are provided which meet so as to form a grid-like network of reasonably continuous horizontal boreholes within the stratum. Thus, the horizontal portion of well 301 meets the horizontal portion of wells 307 and 309 to form a single continuous heated corridor. Some point in the borehole near its entry point into the reservoir is near the termination point of another horizontal well. A similar relationship exists between well 303 and its adjacent brothers and also well 305 and its adjacent wells.

The displacement flow, as shown in FIG. 5B, is more circuitous than in the array illustrated in FIGS. 4A and 4B, but the overall expense is less because of the lower number of wells drilled.

As in FIG. 4B, the wells in rows A and C are used as injection wells and those in rows B and D are producers.

The foregoing disclosure and description of the invention are only illustrative and explanatory thereof. Various changes in size, shape and details of the illustrated construction may be made within the scope of the appended claims without departing from the spirit of the invention.

We claim:

1. A method for treating a field having a reservoir containing viscous oil or bitumen comprising the steps of:

providing at least two boreholes extending downward from the surface at least into the reservoir,

providing at least one generally horizontal borehole within the reservoir connecting at least two boreholes extending from the surface,

introducing a heated fluid into said horizontal borehole in an amount sufficient to at least soften said viscous oil or bitumen for a distance substantially along said at least one generally horizontal borehole within the reservoir,

substantially plugging said at least one horizontal borehole within the reservoir,

introducing a heated displacement fluid into at least one borehole extending downward from the surface within the reservoir at the juncture between the plugged borehole said downwardly extending borehole, and

withdrawing said viscous oil or bitumen from a borehole extending downward from the surface at a point remote from the displacement fluid introduction point.

2. The method of claim 1 wherein said at least two boreholes extending downward from the surface are substantially vertical.

3. The method of claim 1 wherein at least one of the boreholes extending downward from the surface and at least one of said horizontal boreholes within the reservoir are the same borehole.

4. The method of claim 1 wherein the heated fluid is steam.

5. The method of claim 4 wherein steam pressure in said at least one horizontal borehole approaches or is less than the localized fracturing pressure of the reservoir.

6. The method of claim 4 or 5 wherein steam flow is terminated after 50–100 barrels of steam per linear foot of horizontal borehole in the reservoir have been added.

7. The method of claim 1 wherein the reservoir is vertically adjacent a water-containing layer.

8. The method of claim 1 wherein said at least one horizontal borehole is plugged with either cement or a mixture of clay and rock.

9. The method of claim 1 wherein the heated displacement fluid is steam.

10. A method for producing viscous oil or bitumen from a reservoir containing same comprising the steps of:

providing first, second, third and fourth boreholes extending down from the surface at least into the reservoir, spaced apart in a generally rectangular configuration so that the first borehole is on the corner adjacent the second and the fourth on the rectangle,

providing two horizontal boreholes within the reservoir connecting first and second boreholes and third and fourth boreholes,

providing a horizontal borehole connecting the horizontal boreholes between first and second boreholes and third and fourth boreholes approximately at the midpoints between first and second boreholes and third and fourth boreholes,

introducing a heated fluid into each of the horizontal boreholes in an amount sufficient to at least soften said viscous oil or bitumen,

substantially plugging each of said horizontal boreholes within the reservoir,

introducing a heated displacement fluid into first and second boreholes at their junction with the plugged horizontal boreholes,

withdrawing said viscous oil or bitumen from third or fourth boreholes.

11. The method of claim **10** wherein at least one of the heated fluid and the heated displacement fluid is steam.

12. The method of claim **10** wherein the reservoir is vertically adjacent a water-bearing layer.

13. The method of claim **10** wherein the horizontal wellbores are plugged with a material selected from cement and a mixture of clay and rock.

14. A method for treating a field having a reservoir containing viscous oil or bitumen comprising the steps of:

providing a number of generally horizontal boreholes within a reservoir each having an entry point into the reservoir and a termination point within the reservoir, and arranged in a grid-like array with the termination point of a majority of said boreholes each being in near proximity to the entry point of another horizontal borehole,

introducing a heated fluid into each of said horizontal boreholes in an amount sufficient to at least soften said viscous oil or bitumen,

substantially plugging each of said horizontal boreholes within the reservoir.

15. The method of claim **14** wherein the heated fluid is steam.

16. The method of claim **15** wherein steam pressure in said horizontal boreholes approaches or is less than the localized fracturing pressure of the reservoir.

17. The method of claim **15** or **16** wherein steam flow is terminated after 50–100 barrels of steam per linear foot of horizontal borehole in the reservoir have been added.

18. The method of claim **14** wherein the reservoir is vertically adjacent a water-containing layer.

19. The method of claims **14**, **15**, or **18** further comprising the steps of:

introducing a heated displacement fluid into the reservoir at one end of each of said plugged horizontal boreholes,

withdrawing said viscous oil or bitumen at a point on said plugged horizontal boreholes remote from the displacement fluid introduction site.

20. The method of claim **19** wherein the heated displacement fluid is steam.

21. The method of claim **14** wherein each of said horizontal boreholes is plugged with either cement or a mixture of rock and clay.

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(54) METHOD AND APPARATUS FOR FORMING LATERAL PASSAGEWAYS

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to the recovery of hydrocarbons and such other underground values as may be recovered through inaccessible bores. More particularly, it provides new and improved apparatus and method for forming a horizontal or lateral passageway, which may have great length. Such passageway is useful in the recovery of petroleum, more particularly viscous oils and tars, in obtaining bitumens and other semi-solids, in degassing coal seams and in the recovery of any substance which may be disintegrated by the mechanical or hydraulic means disclosed herein and be slurrified.

Description of the Prior Art

The value of the presently uneconomically recoverable reserves of heavy oils and tars is inestimable. The many schemes and inventions disclosed during the past fifty years in an attempt to form lateral bores attest to the dire need for such technology.

The techniques heretofore proposed for forming horizontal or lateral bores suffer major and critical deficiencies. Some presuppose some idealized or homogeneous conditions seldom found in nature. Other require a special combination of strata deposition. Many ideas require pulling the boring means from the horizontal into the vertical well with no provision made for preventing key-seating. It is well known in oil well drilling that a change in hole angle exceeding 8 to 10 degrees per one hundred feet of dog-leg severity will cause stuck pipe.

Recently, a subsidiary of Imperial Oil, Esso Resources Canada Ltd. in seeking to recover heavy oil from the vast deposits at Cold Lake, Alberta, Canada drilled what it claimed to be "the first horizontal well to be drilled in North America and probably in the western world" using conventional drilling equipment in a special manner described in Oilweek, November 12, 1979, pages 68 to 70. A milled tooth bit rotated by a Dynadrill was used to make hole. Bent subs provided the angle build up. The collars were not positioned just above the bit but rather were located in the "more vertical portion of the hole to provide weight on bit". Special "Hevi-wate pipe was used between collars and bit assembly because ordinary drill pipe cannot be used in compression". Oil base mud was used to minimize the tendency of the drill pipe to drag and to reduce the tendency of the curved pipe to stick against the side of the hole. The author of the paper was justifiably proud of the achievement and of the possibilities opened up for improving recovery from the vast heavy oil deposits in North America.

The technology employed, however, was time consuming and costly. Also, there would appear to be limitations as to how far one could proceed in a horizontal direction after it had been attained by pushing a heavy drilling assembly with heavy drill pipe.

Similarly and more recently in an article entitled "Soviets Claim Horizontal Drilling Success", Oil and Gas Journal, December 17, 1979, page 23, the horizontal drilling of the terminal portion of oil wells by the Russians is disclosed. While details are lacking, here again apparently conventional equipment was used but special techniques and procedures employed. The article reports that "the wells [were] spudded at a sharp angle" (apparently using slant drilling rigs) "and completed using turbo drills for horizontal drilling". All that is revealed is that when "the well reaches the projected depth . . . the drill moves horizontally' . . . and "operation of the drill horizontally becomes more difficult." Here, as in the case of Esso Resources, presumably steel drill pipe was used throughout the drilling operation and with all the attendant difficulty of keeping weight on bit as the horizontal portion of the hole was extended.

In an invention relating to solution mining Charles H. Jacoby, U. S. Patent No. 3,873,156, describes a system for coalesing the nether ends of spaced apart bores. He attaches floats to a hydraulic jetting tool and to the flexible conduit conducting the jetting fluid thereto and employs two immiscible liquids of different density to locate the system at an interface.

U. S. Patent No. 2,822, 158, to W. C. Brinton, also relates to fluid mining using both solvent action and mechanical forces. Brinton's tool is advanced by the weight of a flexible, partially flattened steel pipe and does not rotate. Change from vertical to horizontal course is obtained when the tool caroms off a rounded steel post and slides along a hard stratum. A lateral passage is formed by solvent action and through the punching ability of the tool as it is advanced by the weight of the shaft.

C. W. Brandon received U. S. Patent No. 2,796,129 on June 18, 1957 on tunnelling between vertical wells. He included wave pulsations to aid oil recovery. His invention is not related to any particular way for effecting formation of the tunnels but he deems hydraulic methods efficacious.

In U. S. Patent No. 3,844,362, K. E. Elbert et al disclose a rotary boring device stated to be suitable for cleaning conduits or for boring holes. Although not specifically stated the boring tool is obviously metallic and carries a cutting head of a suitable material such as diamonds imbedded in a matrix. A flexible hose delivers fluid to the device and by discharge of the fluid through appropriately positioned nozzles rotation of the cutting head and a tool advancing force are generated.

U. S. Patent No. 142,992 issued September 23, 1873 to C. G. Cross described a drill which rotates by jetting a fluid from a first set of holes into a second set spaced about 90 degrees from the first set. This device is not useful for boring a lateral passageway when using a flexible hollow shaft because the reaction of the tool transmitted to the shaft would cause it to twist and kink to stop flow of drilling fluid therethrough.

J. N. Pew III received U. S. Patent No. 3,070,361 for a fluid mining process in which a tough, flexible, nonmetallic hose provided with a plurality of cleats will flap about due to the forces induced by escape of high pressure water and air to dislodge coal and float same to the surface. Pew's device is not applicable to forming lateral bores.

The prior art also includes U. S. Patent No. 3,964,792 to W. R. Archibald for an explosive shock mining system; U. S. Patent No, 2,515,421 to Robertson disclosing a drilling tool which includes a means inside a vertical bore for positively feeding a drill head and a flexible shaft into rotary cutting position against an earth stratum; U. S. Patent No. 1,628,070 to Sladden for a selfpropelled hose nozzle; U. S. Patent No. 2,710,980 to Pletcher for a pipe cleaning apparatus which is selfpropelled; U. S. Patent No. 4,010,801 to Terry for in situ gassification of coal with lateral passage forming means not disclosed, and U. S. Patent No. 4,109,715 to J. S. Adamson for an articulated system for drilling lateral well bores.

Thus the present invention provides a method for drilling a well bore in a generally horizontal directon from a location in a formation in the earth accessible only via a connecting well bore extending from said location to the earth's surface, comprising utilizing drilling means comprising a flexible shaft conduit adapted to transmit drilling fluid, and having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and conduit to permit relative rotation therebetween and means connected to said boring tool and said conduit for generating upon the passage of energy therethrough conducted by said conduit a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to each have substantially the same specific gravity within the range of from 0.9 to 2.7, and introducing said energy and said drilling fluid through said shaft conduit to cause said tool to rotate and advance, said drilling fluid having a specific gravity substantially the same as the specific gravity of the drilling means, and rendering said drilling means substantially neutrally buoyant in the fluid filling the well bore being drilled.

In another embodiment the invention provides a method for drilling a well bore in a generally horizontal direction from a location in a formation accessible only via a connecting well bore extending from said location to the earth's surface comprising utilizing a set of drilling apparatus comprising a flexible shaft conduit adapted to carry drilling fluid, and having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and conduit to permit relative rotation therebetween and means connected to said boring tool and in fluid communication with said conduit for generating upon the passage of fluid therethrough a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to each having substantially the same average specific gravity within the range of 0.9 to 2.7, and introducing said drilling fluid through said shaft conduit to cause said tool to rotate and advance, said drilling fluid having a specific gravity substantially the same as the specific gravity of the drilling apparatus, and rendering said drilling apparatus substantially neutrally buoyant in the fluid filling the well bore being drilled.

And in still another embodiment there is provided for drilling a well bore in a generally horizontal direction from a location in a formation accessible only via a connecting well bore extending from said location to earth's surface comprising utilizing drilling means comprising a flexible shaft conduit, adapted to carry drilling fluid, a rotary boring tool, and a bearing means interconnecting said boring tool and said conduit, said boring tool having fluid discharge ports so positioned that the passage of fluid therethrough will generate a force tending to advance said boring tool and a force tending to cause said tool to rotate, said shaft conduit, boring tool and bearing being so constructed as to each have substantially the same average specific gravity within the range of from 0.9 to 2.7, and introducing drilling fluid through said shaft conduit to cause said tool to rotate and advance, said drilling fluid, having a specific gravity substantially the same as the specific gravity of the drilling means, and rendering said drilling apparatus substantially neutrally buoyant in the fluid filling the well bore being drilled.

In a different aspect the present invention provides a method of drilling a deviated well bore with a generally horizontal extension in a subsurface strata containing a desired substance utilizing in the drilling of said horizontal extension drilling apparatus comprising a flexible shaft conduit, a rotary boring tool and a bearing means interconnecting said boring tool and said conduit, said boring tool having fluid discharge ports so positioned that the passage of fluid therethrough will generate a force tending to cause said tool to rotate and a force tending to cause said tool to advance, said shaft conduit and boring tool being so constructed as to each have substantially the same average density with the range of from 0.9 to 2.7 grams per milliliter, comprising the steps of:

(a) drilling a well bore extending from the earth's surface to the vicinity of the subsurface strata utilizing a drilling bit, steel drill pipe for conducting drilling fluid thereto and weighted with drill collars, said well bore being deviated so that the lower end thereof is inclined at an angle between about 60 degrees and about 75 degrees from the vertical;

(b) terminating said drilling and circulating through said drill pipe and drilling bit drilling fluid having a density less than the density of the drilling apparatus comprising the rotary boring tool and the flexible shaft conduit until said well bore is filled with drilling fluid of said density;

(c) withdrawing said steel drill pipe, drill collars and drilling bit from said well bore;

(d) introducing into said well bore said rotary boring tool and flexible shaft conduit and allowing them to sink through the drilling fluid until the upper end of the shaft conduit approaches submergence;

(e) connecting steel drill pipe to the upper end of the shaft conduit;

(f) continuing to connect drill pipe and lower the rotary boring tool and shaft conduit until the boring tool reaches the bottom end of the well bore;

(g) resuming circulation of drilling fluid by introducing fluid having a density somewhat greater than the density of the rotary tool and shaft conduit to rotate said tool and to cause it to advance in a forward and upward direction; and

(h) when the direction of advance of said boring tool is generally horizontal reducing the density of the drilling fluid being circulated to a value such that the boring tool and shaft conduit are neutrally buoyant therein while continuing said circulation and drilling.

In another embodiment the present invention provides, in a lateral passageway boring means for forming a branch bore from an inaccessible location in a first well bore wherein a drilling fluid is circulated through said boring means for removal of cutting formed by said boring means from said branch bore, the combination comprising:

(a) a flexible shaft conduit for conducting drilling fluid from said first well bore to a rotary boring tool affixed to the end of said shaft;

(b) means mounted in said boring tool for generating from the passage of drilling fluid therethrough a force tending to advance said boring tool and a force causing said boring tool to rotate;

(c) bearing means interconnecting said boring tool and said shaft conduit for permitting relative rotation therebetween; and

(d) means insertable through said shaft conduit adapted to cooperate with means carried by said boring tool for reversing the direction of rotation of said boring tool.

In a further embodiment the present invention provides a a rotary boring tool comprising:

(a) a generally cylindrical body portion formed from materials having an average density less than 2.7 grams per milliliter;

(b) a cutting element portion fixed to the forward end of the body portion comprising a cutting material embedded in a matrix, said cutting element portion having a density greater than the body portion;

(c) a passageway in said body portion for the entry of drilling fluid and a plurality of passageways in said body portion for the discharge of drilling fluid, at least one of said discharge passageways being so positioned that the discharge of fluid therefrom will be toward the forward end of said body portion and at least one of said discharge passageways being so positioned that the discharge of fluid therefrom will be directed away from the forward end of said body portion, said discharge passageways being so proportioned that more drilling fluid will be discharged away from than towards the forward end so that the net effect of the discharge of fluid from such passageways will be to generate a force tending to move said tool toward the forward end, and

(d) said tool being so proportioned that the relative volume of the body portion to the volume of the cutting element portion is such that the tool may be made neutrally buoyant in a drilling fluid having a density intermediate the densities of the cutting element portion and the body portion.

In another aspect the present invention provides a method for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface utilizing a set of drilling apparatus comprising a flexible shaft conduit having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and conduit to permit relative rotation therebetween and means connected to said boring tool and in fluid communication with said conduit for generating upon the passage of fluid therethrough a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to each have substantially the same average density, comprising the steps of:

a. determining the density of drilling fluid within the range of from 0.9 to 2.16 grams per milliliter desirable for use in drilling said horizontal well bore to remove cuttings and to balance formation pressure;

b. selecting from available sets of drilling apparatus having densities within the range of from 0.9 to 2.7 grams per milliliter, the set having a density closest to the density of the drilling fluid to be used so that the drilling apparatus will be substantially neutrally buoyant therein;

c. introducing the selected set of drilling apparatus through said connecting well to said location;

d. connecting to the end of the shaft conduit remote from said boring tool means for introducing drilling fluid;

e. making up drilling fluid having the determined desired density; and

f. introducing said drilling fluid through said shaft conduit to cause said boring tool to rotate and drill said generally horizontal well bore.

In still another aspect the invention provides a system for drilling a generally horizontal well bore comprising:

a. a nonrotating flexible shaft conduit having a rotary boring tool affixed to the nether end thereof for conducting drilling fluid to said boring tool, said boring tool and said shaft conduit being so constructed as to have substantially the same average density within the range of from 0.9 to 2.7 grams per milliliter whereby said boring tool and conduit may be made neutrally buoyant when immersed in drilling fluid;

b. bearing means for interconnecting said boring tool and the end of said conduit for permitting relative rotation therebween; and

c. means connected to said boring tool and in fluid communication with said conduit actuated by the flow of fluid therethrough for generating a force tending to cause said boring tool to rotate and a force tending to cause said boring tool to advance.

In still a further aspect the invention provides a system for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface for the introduction of drilling fluid for circulation through said drilling system and for the removal of earth cuttings produced by the operation of said drilling system comprising:

a. a flexible shaft conduit for conducting drilling fluid from said connecting well to a rotary boring tool positioned at the nether end of said shaft conduit;

b. means connected to said boring tool and in fluid communication with said shaft conduit for generating from the passage of drilling fluid therethrough a force tending to cause said boring tool to rotate and the sole force of forward thrust tending to cause said rotary boring tool to bear against the formation being drilled and to advance; and

c. means interconnecting said boring tool and said shaft conduit for permitting relative rotation therebetween; said flexible shaft conduit, said boring means and said force generating means being constructed from such materials and in such a manner as to have an average density such that by the selection and use of an appropriate drilling fluid they will be neutrally buoyant therein.

In certain aspects the present invention comprises apparatus and a process for forming generally horizontal or lateral passageways either as an extension of a highly inclined well bore conventionally deviated or via a lateral branch from a vertical, inaccessible well of normal diameter. Basically, the apparatus comprises a rotary boring tool and a hollow shaft for conducting drilling fluid thereto to perform inter alia the functions of cooling the drilling bit and, in return flow around the shaft, carrying the cuttings back to the earth surface.

Among the factors important or essential to successful lateral boring, neutral buoyancy of the boring system which enters the lateral bore is of the highest order. If the materials comprising the boring system were precisely neutrally buoyant, it would be weightless. However, precise neutral buoyancy is not economical to obtain or to maintain and is not necessary for the successful operation and use of the present invention. Substantially neutral buoyancy is all that is required. As used herein, a device is substantially neutrally buoyant when it is submerged in a fluid if its weight is between 80 and 125 percent of the weight of the fluid displaced.

The basic objective of the passageways drilled in accordance with my invention is to penetrate and expose an extended length of a formation having a desired substance, such as heavy oil. The various earth formations exist as generally horizontal strata. A generally horizontal well bore will therefore expose such strata for the production of values therefrom throughout its entire length. Frequently, however, such formations may be inclined as much as 20 degrees from the horizontal. In such cases, especially where the formation of interest is relatively shallow, it may be desirable to incline the lateral passageway slightly to conform to the dip of the formation being drilled and such inclined passageways are encompassed within the scope of my invention.

Neither steel drill pipe, which is the conduit conventionally used to conduct drilling fluid and power to a drilling bit and has a density of from about 7.5 to 7.8 grams/ml. (i.e. a relative density or specific gravity of 7.5 to 7.8) nor conventional drilling bits can be made neutrally buoyant in any liquid feasible for use as a drilling fluid.

The body portion of a neutrally buoyant rotary tool may be cast from a mix of epoxy resin and microballoons to a density as low as 0.80 grams per milliliter. Passages are drilled in the body for entry of drilling fluid and its expulsion through rearwardly facing jet nozzles and forwardly facing water courses. The more dense cutting elements, such as metallic carbides or diamonds, embedded in a suitable matrix are fixed to the body. The relative volumes of the body and the cutting elements are so proportioned that the average density of the boring tool will be within the desired range for neutral buoyancy in drilling fluid.

The entry bore is threaded for joining to a rotating union bearing device with the joint sealed by epoxy. A suitable flexible shaft may be made from any of several low density elastomers such as ultra high molecular weight polyethylene having a density of 0.94 grams per milliliter or a polyurethane elastomer which may range in density from 1.05 to 1.12 grams per milliliter. Such materials may be reinforced with glass, steel, long filament carbon or other fibers for added strength and increased density.

Since in any horizontal drilling system the shaft conduit and the rotary drilling tool are positioned in the same drilling fluid, their densities should be substantially identical. In practical operations the conduit-drilling tool sets should be made up in a plurality of densities matched to densities normally employed for drilling fluids used under various drilling conditions encountered. Typical mud weights and the corresponding densities are as follows:

Mud Weight lbs/gal (U.S.)	Density grams/ml
7.5	0.90
9.0	1.08
10.0	1.20
11.0	1.32
12.0	1.44
13.0	1.56
14.0	1.68
16.0	1.92
18.0	2.16

A high density drilling fluid assists in removal of cuttings from a horizontal bore. However, if the head of fluid on the exposed formation is too great, lost returns will result. This would limit fluid density unless artificial lift were employed to lower the fluid level in the vertical well and this is contemplated herein. The driller would determine the mud weight he wished to employ to balance formation pressure, remove cuttings, etc., and then use the conduit-drilling tool set having the closest density. Typically, conduit-drilling tool sets would be available having densities in the range of from 0.9 to 2.7 grams per milliliter. Periodic measurements would be made of the position of the bit. If it tended to rise from the horizontal, the weight of the drilling mud would be reduced. Conversely, if the bit was tailing off in a downward direction, weighting agent would be added to the mud. The direction of rotation of the bit and the nature and dip of the formations being drilled will also influence the direction of advance. Clockwise rotation will cause the bit to trend to the right, counter clockwise, the reverse.

So long as the system in the lateral bore is substantially neutrally buoyant, by making measurements of bit position and by making appropriate changes in the direction of rotation and the mud weight, a generally horizontal bore of substantial length may be drilled.

Because the shaft conduit must make a 90 degree bend in traversing the well bore from the earth's surface and because it must conform to all undulations in the horizontal bore, flexibility of the shaft is also important for the successful operation of my invention.

Boring of lateral holes is subject to the same controlling factors as vertical drilling, namely weight on the bit or thrust, speed of rotation and drilling fluid circulation rate. However, the amount of useful mechanical power which can be transmitted to the nether end of a flexible conduit is quite limited. This fact restricts both weight on bit and rotary torque. Pushing force on a flexible shaft, even inside the relatively small diameter lateral bore, cannot deliver a useful thrust to the rotary bit. Hence, the feed means is located near the nether extreme of the boring tool and pulls the shaft forward as the hole is bored. Drag on the exterior surface of the shaft is kept to a minimum by having a smooth exterior and by the neutral buoyancy of the shaft. The hydraulic radius of the annulus between the outside of the shaft and the bore wall is designed to provide the lowest possible drag on the shaft by returning drilling fluid consistent with delivery of sufficient power to the rotary bit. Boring progress is related directly to thrust per inch of bit diameter. Thus, the lateral bore is no larger than is necessary to permit acceptable return flow velocity. The diameter of the forward facing water course in the rotary bit is the minimum necessary to provide cooling and lubrication to avoid excessive backward, reactive force.

To add feed or advancing force, impediments to flow may be placed at intervals along the inside of the conduit to convert fluid friction and impact into advancing force.

Where it is desired to drill a lateral well bore at a selected point in a vertical well, the shaft conduit must make a 90 degree bend with a relatively short radius. The physical requirements for a shaft conduit having such flexibility are rather strict and somewhat contradictory. High bursting pressure, and hence high tensile strength, is needed to transmit pressured drilling fluid to advance and rotate the bit. However, the shaft must be highly flexible and this requires relatively low tensile modulus material which usually has low tensile strength. Investigation of a number of materials reveals that a ratio of tensile modulus to tensile strength of less than 40 is required for a satisfactory flexible shaft. Also, the tensile modulus of the shaft should be less than 100,000, and preferably less than 40,000, pounds per square inch. Commercially available hoses quite often are not made from a single material but are composites of several. Bending of the shaft is related to lengthwise tensile modulus of such a composite hose. A simple test was devised to measure this lengthwise modulus. A selected convenient length of hose, say 30 feet, is pressurized and the change in length observed. Hoop stress is calculated from the formula S = P(D -e)/2e (Stress equals pressure times outside diameter minus wall thickness divided by twice the wall thickness.), reference, Modern Plastics Encyclopedia, Volume 54, No. 10A, McGraw-Hill Publisher. Longitudinal stress is one-half hoop stress. This stress divided by fractional change in length gives the lengthwise tensile modulus. For example, a 30-foot length of hose was shortened 3.58 inches when pressured to 82 pounds per square inch, a fractional change of 0.010 in length. Hoop stress was calculated to be 287 psi and hence, longitudinal stress was 143.5 psi. The effective tensile modulus of this hose, measured lengthwise, is 14,350 psi. Tensile strength, calculated from the manufacturer's rated burst pressure was 1575 psi. The ratio of tensile modulus to tensile strength is 9.1.

To assist the shaft to make the turn from vertical to horizontal a shaft bending means may be employed. In one form a powered device urges the nether extreme of the boring tool means into initial horizontal contact with the earth stratum by means of a plurality of rollers in frictional contact therewith. The bending means obviously contributes advancing force to the bit at that time and when the length of lateral hole is short. Too great a force could stall the bit. Hence, a fluid coupling is installed between the prime mover and the rotating rollers. The shaft bending means preferably is reversible to prevent key-seating of the shaft as it is withdrawn from the lateral bore. Another form of shaft-bending means is disclosed and claimed in my U.S. Patent No. 4,303,134 issued December 1, 1981, dealing with an earth boring guide.

By the use of jet nozzles for generating forward thrust, substantially no torque forces are transmitted to the shaft thus permitting the use of a highly flexible shaft capable of making a 90° bend with a short radius.

The advancing force is obtained by aiming the jet discharge toward the rear of the tool, i.e., away from the cutting face. Rotating force or torque is derived by placing the jet nozzles near the periphery of the tool. In axial cross-section the jet nozzle is on a chord of the cylindrical tool and located as near to the outside surface as structural limitations will permit.

In one embodiment of the invention two sets of rearwardly facing jet nozzles may be inserted in the tool in a manner such that the first set causes rotation of the bit in one direction and the second set rotation in the opposite direction. To reverse the rotation the first set of nozzles may be plugged and the second set opened by inserting a device into the shaft at the surface and pumping it into the tool.

The present invention has various applications in the winning of desired substances from subsurface strata. Heat to melt tar and bitumen may be transmitted by means of hot fluids pumped into the lateral bore. Coal may be degassed by reducing pressure in the branch well. Minerals may be comminuted and slurrified to be brought to the surface. The lateral passageway may be designed to cross induced or natural fractures to increase fluid productivity. A lateral bore will reduce coning of undesired fluids by reduction of flowing pressure differential. Efficiency of water-flooding is increased because linear flow between wells is a more effective process than radial flow. Other useful applications will become apparent to those skilled in the art.

Accordingly, one object of this invention is to provide a new means and method for penetrating the earth. Another object is to provide novel apparatus and process for forming lateral passageways from a vertical well. It is still another object to form such passageways to a length not heretofore attainable.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a general view in cross section, partly schematic, showing the invention and related equipment.

Figure 2 is a cross sectional view of a tool and shaft.

Figure 3 is a cross sectional view of the rotary bit taken on the line 3-3 of Figure 2.

Figure 4 is a cross sectional view of the rotary bit taken on the line 4-4 of Figure 2.

Figure 5 is a cross sectional view of a modified shaft.

Figure 6 is a cross sectional view of another modification useful in forming underground cavities.

Figure 7, partly in cross section and partly schematic, shows a shaft bending means used to direct a boring means from a vertical bore into position for forming a lateral passageway.

Figure 8 is a cross sectional view of Figure 7 taken at the line 8-8.

Figure 9 is a cross sectional view of another modification showing the use of the invention for forming a horizontal extension of a conventionally deviated well.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 shows a preferred embodiment of the present invention. Well 1 is drilled through upper earth horizons 2 into earth strata 3 containing desired substance 4. A casing 5 is sealed into strata 3 by cement sheath 6. First tubing string 7 is run into casing 5 and fixed thereto by casing head 8. A low density, flexible shaft conduit 9 having rotary drilling tool 10 affixed to its nether end is run into tubing 7 until tool 10 reaches tube bending means 11. Because casing 5 and tubing 7 contain a drilling fluid 12 in which shaft 9 and tool 10 are neutrally buoyant, pump 13 is used to force drilling fluid 12 through rearwardly facing jets 14 in order to advance drilling tool 10 through conduit 7. Pumping rate is reduced as tool 10 approaches shaft bending means 11, otherwise it might be damaged by the rotating bit 27, Figure 2. However, after tool 10 has passed through bending means 11 and has assumed a horizontal position, full pumping rate is initiated to form branch bore 15 in strata 3. Cuttings 16 and returning drilling fluid 12 pass upwardly through annulus 17 between tubings 7 and 9.

Return fluid flow may be assisted and fluid pressure head on strata 3 reduced by artificial lift of drilling fluid from a below ground level inside casing 5 to the surface. For gas-lift, compressor 18 sends pressured gas 19 through pipe 20 and valve 21 into casing annulus 22 where gas entry into tubing 7 is controlled by gas lift valves 23. Drilling fluid 12 returns flow through pipe 24 and valve 25 into tank 26 which may be closed to operate as a gas-liquid separator. Drilling fluid 12 and cuttings 16 may be separated by a shale shaker, not shown, and the fluid recirculated. In the event that desired substance 4, drilling fluid 12 and cuttings 16 are intimately mixed, various means for separation are available such as heating, solvent extraction and centrifuging, but means of surface recovery does not form a part of the present invention.

Rotary tool 10 is shown in detail in Figure 2. In the preferred embodiment, the tool 10 comprises drag bit 27 having a hardened cutting surface 28 affixed to body 27 by fastenings 29. For use in a drilling fluid having a density of 1.2 grams per milliliter bit 27 may be cast from a mix compound of cycloaliphatic epoxy 61 parts, microballoons 31 parts and glass fibers 5 parts by volume with steel trim 2.5 parts and tungsten carbide 0.5 parts added after drilling suitable fluid passageways. Body 27 is covered with two layers of Vectra*cloth 30, a polypropylene fabric sold by National Plastics Products Company, applied with epoxy resin, to improve abrasion resistance.

Central fluid passage 31 is formed, bores 32 and 33 drilled to connect thereto and water courses 34 also penetrate to the central passage 31. Bores 32 and 33 face toward the rear so that expulsion of drilling fluid at high velocity imparts an advancing force to tool 10.

*Trademark

Bores 32 and 33 not only face rearwardly as shown in Figure 2, but also are axially inclined in opposite directions as shown in Figures 3 and 4 so that the discharge of fluid therefrom creates a tangential force tending to rotate bit 27. The diameter of bores 32 and 33 is 10 millimeters while water courses 34 have a diameter of 2.4 millimeters. Bores 34 direct a jet fluid 12 toward cutting edge 28 for cooling and to remove cuttings. Tubes 35 having hardened jet nozzles 36 in their exterior end are cemented, or otherwise fixed, into bores 32 and 33. Smaller diameter tubes 37 are cemented into water courses 34. The end 38 of tubes 37 which extends into passageway 31 is shaped and sharpened to penetrate a seal as described later. The end of bit 27 away from cutting edge 28 is fitted with threads 39 to engage mating threads 40 of rotating union 41 which has been attached to shaft 9 by means of adhesive 43. Indentations 42 are for a spanner wrench, now shown, for tightening the threaded connection 39-40.

Bore holes 32 initially are closed by means of annular ring 44 having O-ring seals 45. When it is desired to reverse the direction of rotation of tool 10, an actuating device 46 is pumped through tubing 9 to contact annular ring 44 and move it outwardly to open bores 32 and simultaneously close bores 33. Device 46 is closed at its advancing end by sealing disk 47 which, being made from soft material, is easily penetrated by the sharp end 38 of tube 37. Cups 48 and centralizing guide 49 assure movement of device 46 through conduit 9 and into tool 10. After device 46 is seated in tool 10 passages 34 receive fluid 12 as before and fluid ejection through bores 32 causes the tool 10 to rotate in the opposite direction.

Shaft conduit 9 may be formed from a glass reinforced polyethylene plastic to have a density of 1.20 grams per milliliter, a tensile modulus of 25,000 pounds per square inch and a tensile strength, determined in burst, of 3,600 pounds per square inch. Conduit 9 conveniently is wound on reel 50 and connected to fluid pump 13 by means of tube 51 and valve 52. Rotary tool 10 may have its advance stopped, or be retracted, by manipulation of reel 50. Branch bore 15 may be enlarged by the hydraulic action of drilling fluid ejected through jet nozzles 36, particularly if the tool 10 is not permitted to advance by reel 50.

In another embodiment of this invention, shown in Figure 5, only enough flexible shaft conduit 9 is used to reach the nether end of branch bore 15 from well 1. The conduit which always remains inside tubing 7 may be a steel tubing 53 to permit use of higher circulating pressures safely. Steel tubing 53 is handled in the normal way and eliminates the use of reel 50. Tubing 53 is joined to coupling 54 by mating threads 55 and shaft 9 is fixed to the lower end of coupling 54 by adhesive cement joint 56 reinforced by self-tapping screws 57.

Figure 6 shows an embodiment of the invention adapted for use in forming a large underground cavity from a vertical, inaccessible well. Producing well 1 penetrates formation 3 to recover desired substance 4. A modified tube bending means 58 is run on the lower end of casing 5. Power extracted from pressured drilling fluid 12 advances tool 10 while fastenings 61 across annulus 62 assure simultaneous advance of flexible conduits 59 and 60 and of bearing 41. Returning drilling fluid 12 laden with cuttings 16 and desired substance 4 flows through annulus 62 into well 1 and exits through outlet 63 into casing 5 whence it enters ports 64 of centrifugal pump 65 driven by electric motor 66 and is lifted to the surface thereby. Control of rate of pumping by pump 65 determines the working fluid level 67 in casing 5 and hence fluid pressure head on formation 3.

A powered tube bending means is shown in Figures 7 and 8. Casing 5 and cement sheath 6 have window 142 therethrough to expose formation 3.. Auxilliary tubing 7 having elbow outlet 143 with power system 144 spaced immediately below are lowered into well 1 until outlet 143 is opposite window 142. Outlet 143 may be oriented by means well known in petroleum drilling. The power system 144 includes an electric motor 145 driving a fluid coupling 146 which delivers a constant torque to speed reducing gear 147 carrying sheaves 148 which drive cogged belt 149 in the direction shown by arrows in Figure 7 to cause rollers 150 to turn in a clockwise direction while cogged belt 151 causes other rollers to rotate counterclockwise. The four powered rollers 150 and the four unpowered rollers 152 cooperate to cause conduit 9 to move downwardly and outwardly to put tool 10 into contact with formation 3. Rollers 150 and 152 are mounted on bearing 153 and shaft 154 while cogged belts conveniently may pass through slots cut into tubing 7. Electrical conductor 155 transmits power from the surface to motor 145. Rollers 156 provide additional guidance to conduit 9.

Figure 9 illustrates my invention in its application to the lateral extension of a deviated well bore. Deviated wells and the techniques for drilling such wells are well known. Primarily the deviated well is used in situations where it is impractical, impossible or uneconomic to position a drilling rig over the spot where it is desired to bottom a well. Advantageously, the Dyna-Drill,* available from the DYNA-DRILL Company, Irvine, California, a division of Smith International, Inc. is used. The Dyna-Drill and equivalent mud turbine powered rotary bit systems used for drilling deviated holes employ conventional steel drill pipe and forward thrust for the rotary drilling bit is obtained by applying the weight of drill collars to the bit.

*Trademark

As shown in Figure 9 it is not necessary to deviate the well a full 90 degrees before using my invention to form a generally horizontal extension thereof. Well 100 is spudded and surface casing 102 set and cemented as shown at 104. Deviated drilling is then initiated and when the well reaches the formation 106 above the strata 107 wherein a horizontal bore is desired, intermediate casing 108 is run in and cemented as shown at 110. Deviated drilling with the Dyna-Drill is then continued into strata 107 to point 112 where the hole approaches the horizontal and forward progress is restricted by the difficulty in maintaining weight on the bit. Rather than attempt to deviate the hole a full 90 degrees, when the hole has been deviated between 60 degrees and 75 degrees, the use of the system of the present invention become more advantageous than continuing the use of drill collars to apply the advancing force on the bit.

After the Dyna-Drill is removed from the hole, the drilling tool 10 of the present invention is attached to the flexible shaft 9 which in turn is connected to conventional drill pipe 53 as shown in Figure 4 and run into the hole to bottom. Before running the drilling tool into the hole, it is desirable to condition the drilling fluid to a density somewhat less than the density of the drilling tool and flexible shaft. This ensures that they will sink through the fluid to the bottom as they are lowered by the introduction of the drill pipe into the hole. Drilling fluid is then weighted to a density slightly greater than the average densities of the flexible shaft and drilling tool. The drilling tool will thus tend to float in the drilling fluid and advance forwardly and upwardly. When the direction of advance is substantially horizontal, the weight of the drilling fluid may be reduced and thereafter the bit will advance in a substantially horizontal direction.

Since many modifications and possible embodiments and uses may be made of the apparatus of this invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown is to be interpreted as illustrative not as limiting.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for drilling a well bore in a generally horizontal direction from a location in a formation in the earth accessible only via a connecting well bore extending from said location to the earth's surface, comprising utilizing drilling means comprising a flexible shaft conduit adapted to transmit drilling fluid, and having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and conduit to permit relative rotation therebetween, and means connected to said boring tool and said conduit for generating upon the passage of energy therethrough conducted by said conduit a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to have an average specific gravity within the range of from 0.9 to 2.7, and introducing said energy and said drilling fluid through said shaft conduit to cause said tool to rotate and advance, said drilling fluid having a specific gravity substantially the same as the specific gravity of the drilling means, and rendering said drilling means substantially neutrally buoyant in the fluid filling the well bore being drilled.

2. A method for drilling a well bore in a generally horizontal direction from a location in a formation accessible only via a connecting well bore extending from said location to the earth's surface comprising utilizing a set of drilling apparatus comprising a flexible shaft conduit adapted to carry drilling fluid, and having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool

and conduit to permit relative rotation therebetween and means connected to said boring tool and in fluid communication with said conduit for generating upon the passage of fluid therethrough a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to have an average specific gravity within the range of 0.9 to 2.7, and introducing said drilling fluid through said shaft conduit to cause said tool to rotate and advance, said drilling fluid having a specific gravity substantially the same as the specific gravity of the drilling apparatus, and rendering said drilling apparatus substantially neutrally buoyant in the fluid filling the well bore being drilled.

3. A method for drilling a well bore in a generally horizontal direction from a location in a formation accessible only via a connecting well bore extending from said location to earth's surface comprising utilizing drilling means comprising a flexible shaft conduit, adapted to carry drilling fluid, a rotary boring tool, and a bearing means interconnecting said boring tool and said conduit, said boring tool having fluid discharge ports so positioned that the passage of fluid therethrough will generate a force tending to advance said boring tool and a force tending to cause said tool to rotate, said shaft conduit, boring tool and bearing being so constructed as to have an average specific gravity within the range of from 0.9 to 2.7, and introducing drilling fluid through said shaft conduit to cause said tool to rotate and advance, said drilling fluid, having a specific gravity substantially the same as the specific gravity of the drilling means, and rendering said

drilling means substantially neutrally buoyant in the fluid filling the well bore being drilled .

4. A method for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface, comprising:

utilizing a set of drilling apparatus comprising a flexible shaft conduit adapted to transmit drilling fluid, a rotary boring tool and bearing means interconnecting said boring tool and conduit each so constructed as to have substantially the same specific gravity,said boring tool having fluid discharge ports so positioned that the passage of fluid therethrough will generate a force tending to advance said boring tool and a force tending to cause said tool to rotate;

selecting for use a drilling fluid having a density within the range of from 0.9 to 2.16 grams per milliliter, desirable for use in drilling said horizontal well bore to remove earth cuttings and to balance formation pressure;

selecting from available drilling parts having densities within the range of from 0.9 to 2.7 grams per milliliter, a set having a density closest to the density of the drilling fluid to be used so that the drilling apparatus will be substantially neutrally buoyant therein; and

introducing said drilling fluid through said shaft conduit to cause said boring tool to rotate and drill said generally horizontal well bore.

5. A method for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface utilizing a set of drilling apparatus comprising a flexible shaft conduit having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and shaft conduit to permit relative rotation therebetween and means connected to said boring tool and in fluid communication with said shaft conduit for generating upon the passage of fluid therethrough a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to each have substantially the same average density, comprising the steps of:

a. determining the density of drilling fluid within the range of from 0.7 to 2.16 grams per milliliter desirable for use in drilling said horizontal well bore to remove cuttings and to balance formation pressure;

b. selecting from available sets of drilling apparatus having densities within the range of from 0.9 to 2.7 grams per milliliter, the set having a density closest to the density of the drilling fluid to be used so that the drilling apparatus will be substantially neutrally buoyant therein;

c. introducing the selected set of drilling apparatus through said connecting well to said location;

d. connecting to the end of the shaft conduit remote from said boring tool means for introducing drilling fluid;

e. making up drilling fluid having the determined desired density; and

f. introducing said drilling fluid through said shaft conduit to cause said boring tool to rotate and drill said generally horizontal well bore.

6. A method for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface utilizing a set of drilling apparatus comprising a flexible shaft conduit having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and shaft conduit to permit relative rotation therebetween and means connected to said boring tool and said shaft conduit for generating upon the passage therethrough of energy conducted by said shaft conduit a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to each have substantially the same average density, comprising the steps of:

a. determining the density of drilling fluid within the range of from 0.9 to 2.16 grams per milliliter desirable for use in drilling said horizontal well bore to remove cuttings and to balance formation pressure;

b. selecting from available sets of drilling apparatus having densities within the range of from 0.9 to 2.7 grams per milliliter, a set having a density closest to the density of the drilling fluid to be used so that the drilling apparatus will be substantially neutrally buoyant therein;

c. introducing the selected set of drilling apparatus through said connecting well to said location;

d. connecting to the end of the shaft conduit remote from said boring tool means for introducing energy and drilling fluid;

e. making up drilling fluid having the determined desired density; and

f. introducing energy and said drilling fluid through said shaft conduit to cause said boring tool to rotate and to drill said generally horizontal well bore.

7. A method of drilling a deviated well bore with a generally horizontal extension in a subsurface strata containing a desired substance utilizing in the drilling of said horizontal extension drilling apparatus comprising a flexible shaft conduit, a rotary boring tool and a bearing means interconnecting said boring tool and said conduit, said boring tool having fluid discharge ports so positioned that the passage of fluid therethrough will generate a force tending to cause said tool to rotate and a force tending to cause said tool to advance, said shaft conduit and boring tool being so constructed as to have an average density within the range of from 0.9 to 2.7 grams per milliliter, comprising the steps of:

a. drilling a well bore extending from the earth's surface to the vicinity of the subsurface strata utilizing a drilling bit, steel drill pipe for conducting drilling fluid thereto and weighted with drill collars, said well bore being deviated so that the lower end thereof is inclined at an angle between about 60 degrees and about 75 degrees from the vertical;

b. terminating said drilling and circulating through said drill pipe and drilling bit drilling fluid having a density less than the density of the drilling apparatus comprising the rotary boring tool and the flexible shaft conduit until said well bore is filled with drilling fluid of said density;

c. withdrawing said steel drill pipe, drill collars and drilling bit from said well bore;

d. introducing into said well bore said rotary boring tool and flexible shaft conduit and allowing them to sink through the drilling fluid until the upper end of the shaft conduit approaches submergence;

e. connecting steel drill pipe to the upper end of the shaft conduit;

f. continuing to connect drill pipe and lower the rotary boring tool and shaft conduit until the boring tool reaches the bottom end of the well bore;

g. resuming circulation of drilling fluid by introducing fluid having a density somewhat greater than the density of the rotary tool and shaft conduit to rotate said tool and to cause it to advance in a forward and upward direction; and

h. when the direction of advance of said boring tool is generally horizontal reducing the density of the drilling fluid being circulated to a value such that the boring tool and shaft conduit are neutrally buoyant therein while continuing said circulation and drilling.

8. The method of drilling a deviated well bore with a generally horizontal extension in a subsurface strata containing a desired substance, utilizing in the drilling of said horizontal extension a set of drilling apparatus comprising a flexible shaft conduit having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and said shaft conduit to permit relative rotation therebetween and means connected to said boring tool and in fluid communication with said shaft conduit for generating upon the passage of fluid therethrough a force tending to advance said boring tool and a force tending to cause said boring tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to have an average density within the range of from 0.9 to 2.7 grams per milliliter, comprising the steps of:

a. drilling a well bore extending from the earth's surface to the vicinity of the subsurface strata utilizing a drilling bit, steel drill pipe for conducting drilling fluid thereto and weighted with drill collars, said well bore being deviated so that the lower end thereof is inclined at an angle between about 60 degrees and about 75 degrees from the vertical;

b. terminating said drilling and circulating through said drill pipe and drilling bit drilling fluid having a density less than the density of the drilling apparatus comprising the rotary boring tool and the shaft conduit until said well bore is filled with drilling fluid of said density;

c. withdrawing said steel drill pipe, drill collars and drilling bit from said well bore;

d. introducing into said well bore said rotary boring tool and shaft conduit and allowing them to sink through the drilling fluid until the upper end of the shaft conduit approaches submergence;

e. connecting steel drill pipe to the upper end of the shaft conduit;

f. continuing to connect drill pipe and lower the rotary boring tool and shaft conduit until the boring tool reaches the bottom end of the well bore;

g. resuming circulation of drilling fluid by introducing fluid having a density somewhat greater than the density of the rotary tool and shaft conduit to rotate said tool and to cause it to advance in a forward and upward direction; and

h. when the direction of advance of said boring tool is generally horizontal reducing the density of the drilling fluid being circulated to a value such that the boring tool and shaft conduit are neutrally buoyant therein while continuing said circulation and drilling.

9. The method of drilling a deviated well bore with a generally horizontal extension in a subsurface strata containing a desired substance utilizing in the drilling of said horizontal extension a set of drilling apparatus comprising a flexible shaft conduit having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and said conduit to permit relative rotation therebetween and means connected to said boring tool and said conduit for generating upon the passage therethrough of energy conducted by said conduit a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to have an average density within the range of from 0.9 to 2.7 grams per milliliter comprising the steps of:

a. drilling a well bore extending from the earth's surface to the vicinity of the subsurface strata utilizing a drilling bit, steel drill pipe for conducting drilling fluid thereto and weighted with drill collars, said well bore being deviated so that the lower end thereof is inclined at an angle between about 60 degrees and about 75 degrees from the vertical;

b. terminating said drilling and circulating through said drill pipe and drilling bit drilling fluid having a density less than the density of the drilling apparatus comprising the rotary boring tool and the flexible shaft conduit until said well bore is filled with drilling fluid of said density;

c. withdrawing said steel drill pipe, drill collars and drilling bit from said well bore;

d. introducing into said well bore said rotary boring tool and shaft conduit and allowing them to sink through the drilling fluid until the upper end of the shaft conduit approaches submergence;

e. connecting steel drill pipe to the upper end of the shaft conduit;

f. continuing to connect drill pipe and lower the rotary boring tool and shaft conduit until the boring tool reaches the bottom end of the well bore;

g. making up drilling fluid having a density somewhat greater than the density of the rotary tool, the force generating means and the flexible shaft;

h. introducing energy and the drilling fluid made up in step (g) through said conduit to said force generating means and rotary tool to cause said rotary tool to advance in a forward and upward direction; and

i. when the direction of advance of said boring tool has become generally horizontal reducing the density of the drilling fluid being circulated to a value such that the boring tool, force generating means and shaft conduit are neutrally buoyant therein while continuing said circulation and drilling.

10. A rotary boring tool comprising:

a. a generally cylindrical body portion formed from materials having an average density less than 2.7 grams per milliliter;

b. a cutting element portion fixed to the forward end of the body portion comprising a cutting material embedded in a matrix, said cutting element portion having a density greater than the body portion;

c. a passageway in said body portion for the entry of drilling fluid and a plurality of passageways in said body portion for the discharge of drilling fluid, at least one of said discharge passageways being so positioned that the discharge of fluid therefrom will be toward the forward end of said body portion and at least one of said discharge passageways being so positioned that the discharge of fluid therefrom will be directed away from the forward end of said body portion, said discharge passageways being so proportioned that more drilling fluid will be discharged away from than towards the forward end so that the net effect of the discharge of fluid from such passageways will be to generate a force tending to move said tool toward the forward end, and

d. said tool being so proportioned that the relative volume of the body portion to the volume of the cutting element portion is such that the tool may be made neutrally buoyant in a drilling fluid having a density intermediate the densities of the cutting element portion and the body portion.

11. A self-advancing rotary boring tool comprising:

a. a generally cylindrical body portion formed from materials having an average density less than 2.7 grams per milliliter;

b. a cutting element portion fixed to the forward end of the body portion comprising a cutting material embedded in a matrix, said cutting element portion having a density greater than the body portion;

c. at least one passageway extending through said body portion and the forward end thereof for the transmission of and discharge of drilling fluid across the cutting element portion;

d. means connected to said body portion adapted to conduct drilling fluid and actuated by the passage therethrough and discharge therefrom of drilling fluid to generate forces causing said boring tool to rotate and to tend to advance; and

e. said boring tool being so proportioned that the relative volumes of the body portion, the rotating and advancing force generating means and the cutting element portion are such that the tool may be made neutrally buoyant in a drilling fluid having a density intermediate the densities of the cutting element portion and the body portion.

12. A system for drilling a generally horizontal well bore comprising:

a. a nonrotating flexible shaft conduit having a rotary boring tool affixed to the nether end thereof for conducting drilling fluid to said boring tool, said boring tool and said shaft conduit being so constructed as to have an average density within the range of from 0.9 to 2.7 grams per milliliter whereby said boring tool and conduit may be made neutrally buoyant when immersed in drilling fluid;

b. bearing means for interconnecting said boring tool and the end of said conduit for permitting relative rotation therebetween; and

c. means connected to said boring tool and in fluid communication with said conduit actuated by the flow of fluid therethrough for generating a force tending to cause said boring tool to rotate and a force tending to cause said boring tool to advance.

13. A system for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface for the introduction of drilling fluid for circulation through said drilling system and for the removal of earth cuttings produced by the operation of said drilling system comprising:

a. a flexible shaft conduit for conducting drilling fluid from said connecting well to a rotary boring tool positioned at the nether end of said shaft conduit:

b. means connected to said boring tool and in fluid communication with said shaft conduit for generating from the passage of drilling fluid therethrough a force tending to cause said boring tool to rotate and the sole force of forward thrust tending to cause said rotary boring tool to bear against the formation being drilled and to advance; and

c. means interconnecting said boring tool and said shaft conduit for permitting relative rotation therebetween; said shaft conduit, said boring means and said force generating means being constructed from such materials and in such a manner as to have an average density such that by the selection and use of an appropriate drilling fluid they will be neutrally buoyant therein.

14. In a lateral passageway boring means for forming a branch bore from an inaccessible location in a first well bore wherein a drilling fluid is circulated through said boring means for removal of cuttings formed by said boring means from said branch bore, the combination comprising:

a. a flexible shaft conduit for conducting drilling fluid from said first well bore to a rotary boring tool affixed to the end of said shaft;

b. means mounted in said boring tool for generating from the passage of drilling fluid therethrough a force tending to advance said boring tool and a force causing said boring tool to rotate; and

c. bearing means interconnecting said boring tool and said shaft conduit for permitting relative rotation therebetween;

said shaft conduit and said boring means being constructed from materials and in such a manner as to have an average density such that they are neutrally buoyant in the drilling fluid.

15. The lateral passageway boring means of claim 14 wherein the minimum bending radius of the shaft conduit is less than the diameter of the first well bore.

16. The system for drilling of claim 14 in which the tensile modulus of said shaft conduit in a lengthwise direction does not exceed 40,000 pounds per square inch.

17. The system for drilling of claim 14 in which the ratio of lengthwise tensile modulus to tensile strength of said shaft conduit does not exceed a numerical value of forty.

18. A method for drilling a well bore in a generally horizontal direction from a location in the earth accessible only via a connecting well bore extending from said location to the earth's surface utilizing a set of drilling apparatus comprising a flexible shaft conduit having affixed to the nether end thereof a rotary boring tool with bearing means interconnecting said boring tool and conduit to permit relative rotation therebetween and means connected to said boring tool and said conduit for generating upon the passage of energy therethrough conducted by said conduit a force tending to advance said boring tool and a force tending to cause said tool to rotate, said boring tool, shaft conduit and force generating means being so constructed as to have an average density substantially within the range of from 0.9 to 2.7 grams per milliliter comprising the steps of:

a. introducing said rotary tool and connected shaft conduit through said connecting well to said location;

b. connecting to the other end of said shaft conduit means for introducing energy and drilling fluid thereinto;

c. making up drilling fluid to a density substantially the same as the density of the drilling apparatus; and

d. introducing said energy and said drilling fluid through said shaft conduit to cause said tool to rotate and advance and to render said drilling apparatus substantially neutrally buoyant in the fluid filling the well bore being drilled.

19. A system for drilling a generally horizontal well bore comprising:

a. rotary boring tool comprising:

i. a generally cylindrical body portion formed from materials having average density less than 2.7 grams per milliliter;

ii. a cutting element portion fixed to the forward end of the body portion comprising a cutting material embedded in a matrix, said cutting element portion having a density greater than the body portion;

iii. said body portion and said cutting element portion being so proportioned that the boring tool may be made neutrally buoyant in a drilling fluid having a density intermediate the densities of the cutting element portion and the body portion;

b. a flexible shaft conduit having a density such that it will be neutrally buoyant in a drilling fluid in which the boring tool is neutrally buoyant;

c. bearing means for interconnecting said boring tool and the end of said conduit for permitting relative rotation therebetween; and

d. means connected to said boring tool and in fluid communication with said conduit actuated by the flow of fluid therethrough for generating a force tending to cause said boring tool to rotate and a force tending to cause said boring tool to advance.

20. A system for drilling a well bore in an earth formation in a generally horizontal direction comprising:

a. a rotary boring tool comprising:

i. a generally cylindrical body portion formed from materials having average density less than 2.7 grams per milliliter;

ii. a cutting element portion fixed to the forward end of the body portion comprising a cutting material embedded in a matrix, said cutting element portion having a density greater than the body portion;

iii. said body portion and said cutting element portion being so proportioned that the boring tool may be made neutrally buoyant in a drilling fluid having a density intermediate the densities of the cutting element portion and the body portion;

b. a flexible shaft conduit for conducting drilling fluid and energy to said boring tool and having a density such that it will be neutrally buoyant in a drilling fluid in which the boring tool is neutrally buoyant;

c. bearing means interconnecting said boring tool and the end of said conduit for permitting relative rotation therebetween and providing a passageway for drilling fluid from said conduit to said boring tool; and

d. means connected to said boring tool and said conduit actuated by energy delivered by the conduit for generating a force tending to cause said boring tool to rotate and a force tending to cause said boring tool to advance.

V 4

21. A system for drilling a well bore in an earth formation in a generally horizontal direction comprising:

a. a rotary boring tool;

b. a flexible shaft conduit for conducting drilling fluid and energy;

c. bearing means interconnecting said boring tool and the end of said conduit for permitting relative rotation therebetween and providing a passageway for drilling fluid from said conduit to said boring tool;

d. means connected to said boring tool and said conduit actuated by energy delivered by the conduit for generating a force tending to cause said boring tool to rotate and a force tending to cause said boring tool to advance, and

e. said boring tool, said shaft conduit and said force generating means being so constructed as to have an average density within the range of from 0.9 to 2.7 grams per milliliter whereby said system may be made substantially neutrally buoyant in a drilling fluid having a density within the range of from 0.9 to 2.16 grams per milliliter."

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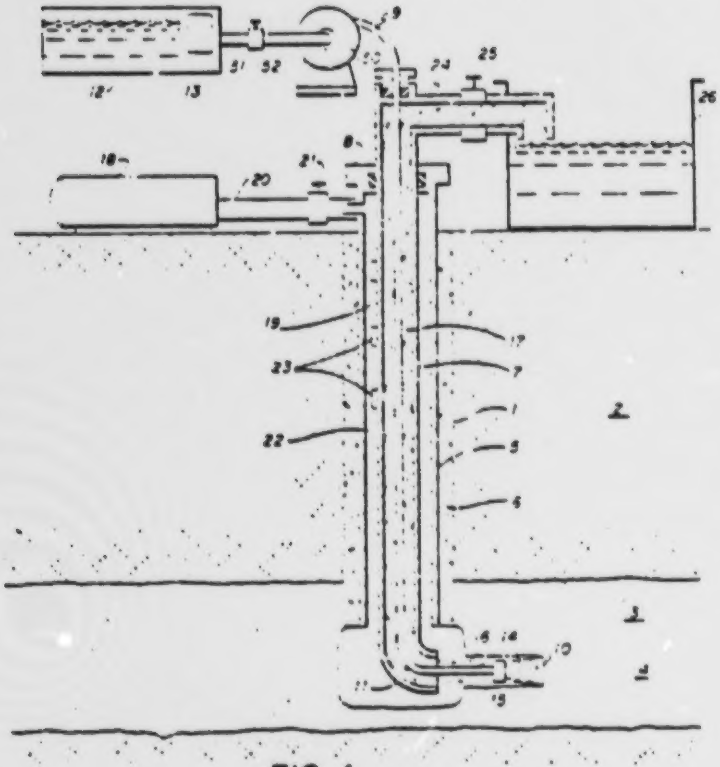
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FIG. 1

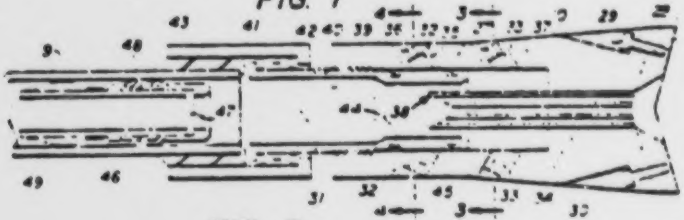
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FIG. 2

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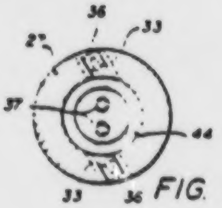
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37
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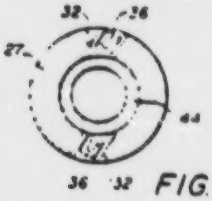
FIG. 3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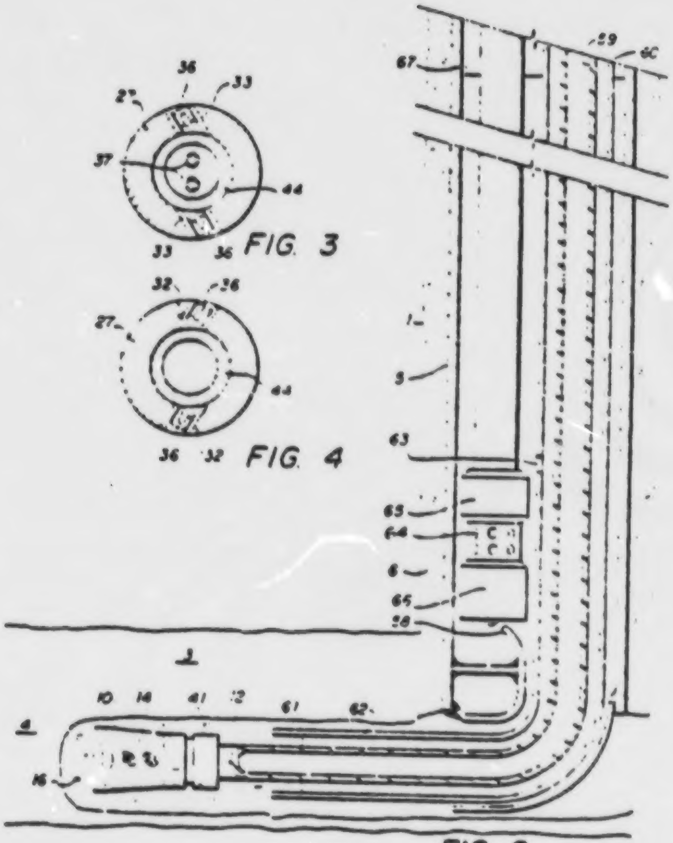
36
32

FIG. 4


67
29
60
1
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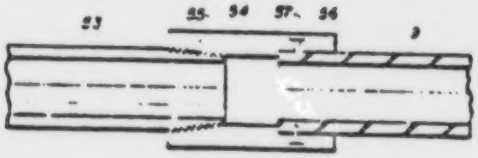
63
63
64
6
65
28
2
10
14
41
12
61
62
4
16

FIG. 6


23
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36
9

FIG. 5

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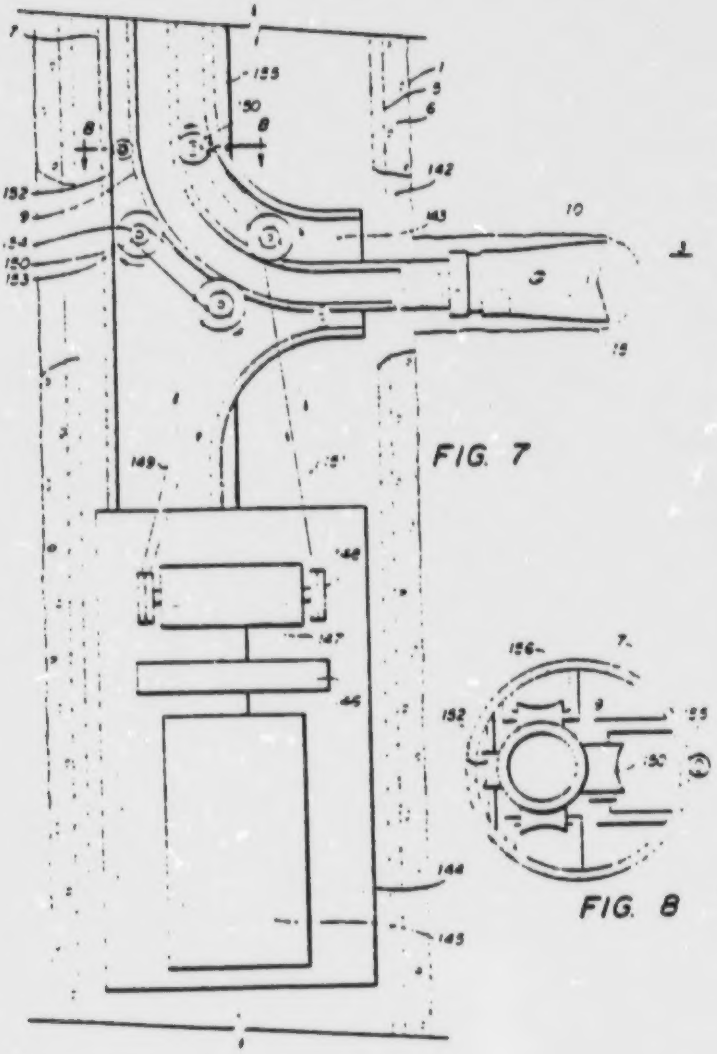
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155
1
5
6
8
150
8
142
152
9
154
150
153
143
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2
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FIG. 7

156
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FIG. 8

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11[illegible]
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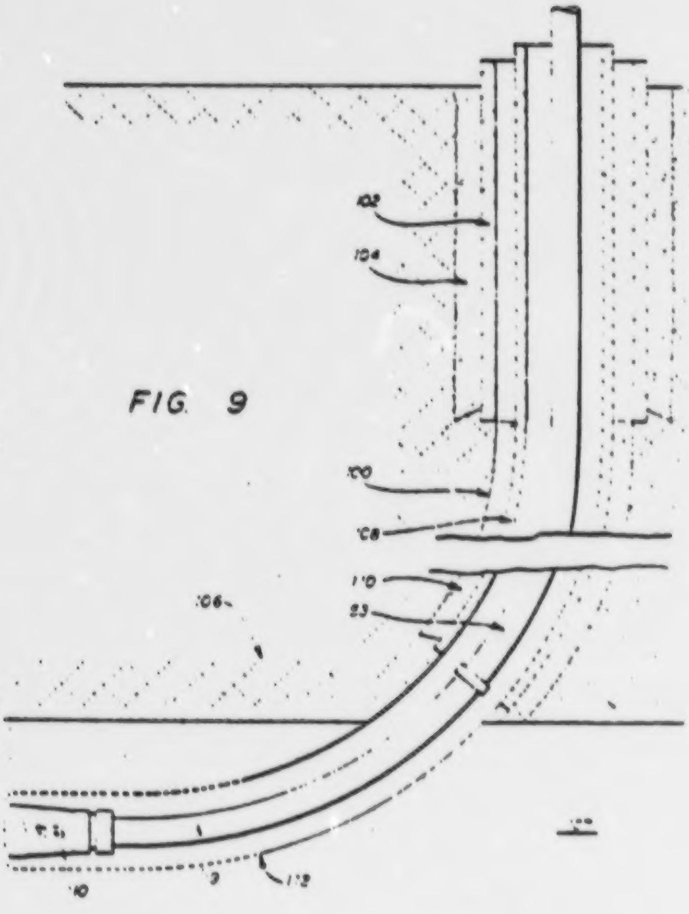
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23
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112

FIG. 9

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Alberta OIL SANDS
INFORMATION CENTRE

United States Patent [19]

Allen

[11] **4,410,216**

[45] **Oct. 18, 1983**

[54] METHOD FOR RECOVERING HIGH VISCOSITY OILS

[75] Inventor: **Joseph C. Allen, Bellaire, Tex.**

[73] Assignee: **Heavy Oil Process, Inc., Dallas, Tex.**

[21] Appl. No.: **267,469**

[22] Filed: **May 27, 1981**

Related U.S. Application Data

[63] Continuation of Ser. No. 108,815, Dec. 31, 1979, abandoned, which is a continuation-in-part of Ser. No. 940,390, Sep. 7, 1978, Pat. No. 4,257,650.

[51] **Int. Cl.³** **E21B 43/24; E21B 43/30; E21B 47/00; E21C 41/10**

[52] **U.S. Cl.** **299/2**; 166/50; 166/245; 166/252; 166/263; 166/272

[58] **Field of Search** 166/50, 57, 62, 245, 166/256, 257, 261, 263, 272, 302, 303, 274, 252; 299/2

[56] **References Cited**

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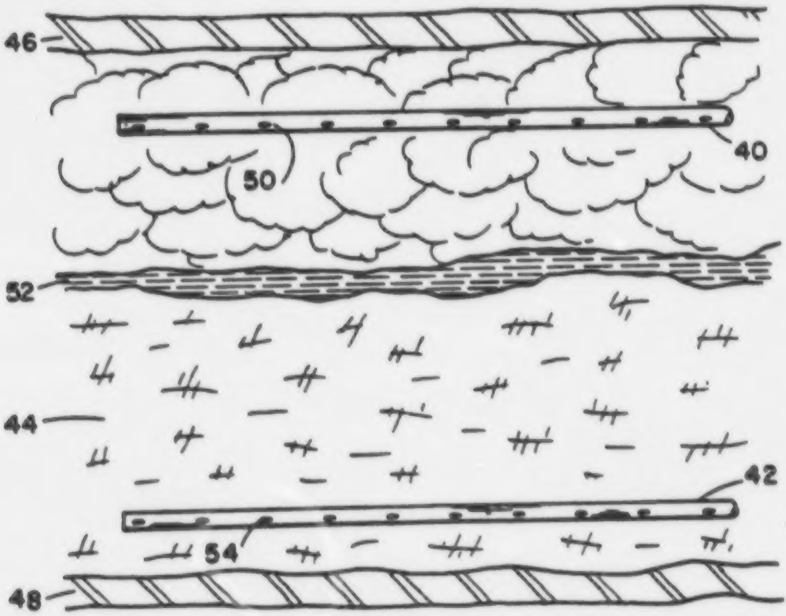
Primary Examiner—Stephen J. Novosad
Assistant Examiner—George A. Suchfield
Attorney, Agent, or Firm—Bard, Groves, Sroufe, Bishop & Berger

[57] ABSTRACT

Improved methods and apparatus are provided for recovering high viscosity oils from sub-surface earth formations. In particular, a large diameter shaft hole is employed and a plurality of substantially horizontal drill holes extend radially from the shaft hole into the formation. It is a feature of this invention to provide vertically spaced drill holes oriented to improve the recovery of the oil. Methods are provided for further enhancing oil recovery by coordinating the injected fluid with the location of injection within the formation.

14 Claims, 6 Drawing Figures



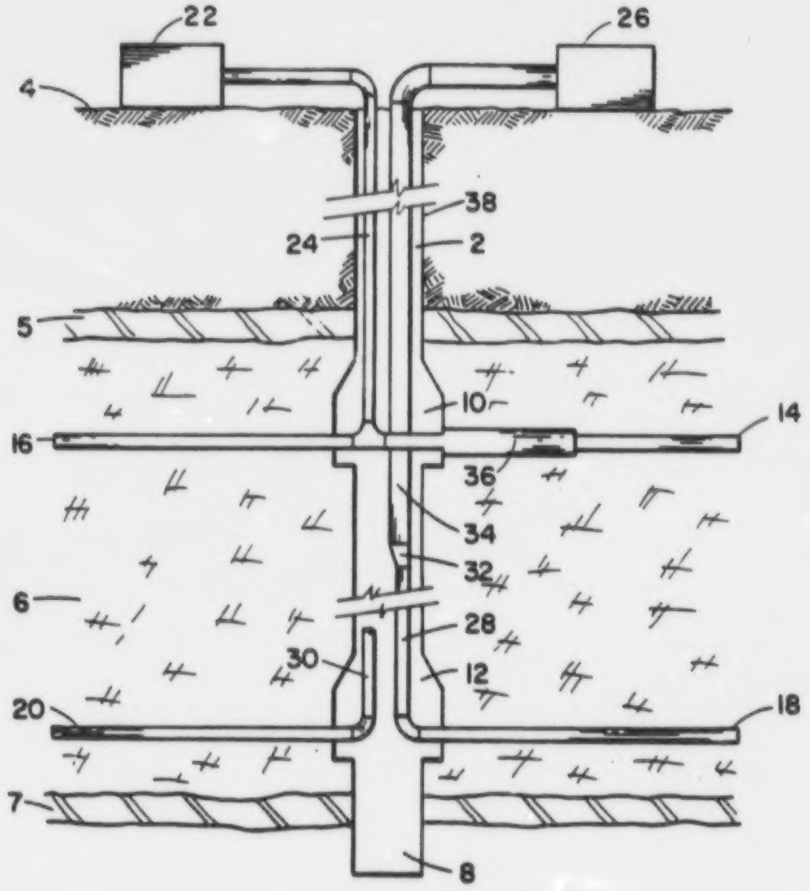


FIG. 1

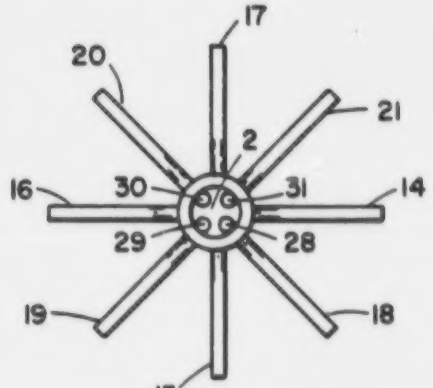


FIG. 2

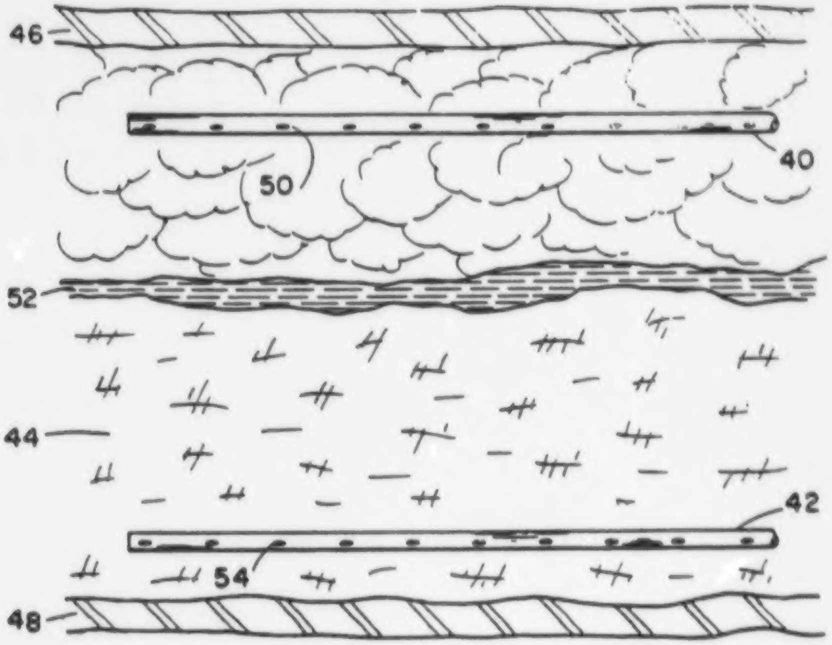

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FIG. 3

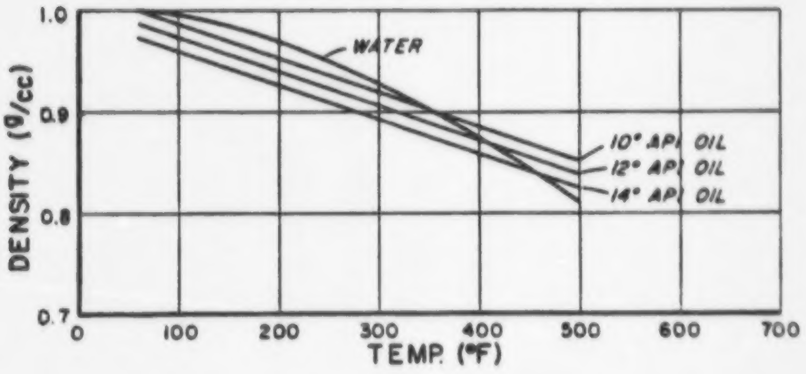
1.0
0.9
0.8
0.7
DENSITY (g/cc)
0
100
200
300
400
500
600
700
TEMP. (°F)
WATER
10° API OIL
12° API OIL
14° API OIL

FIG. 4

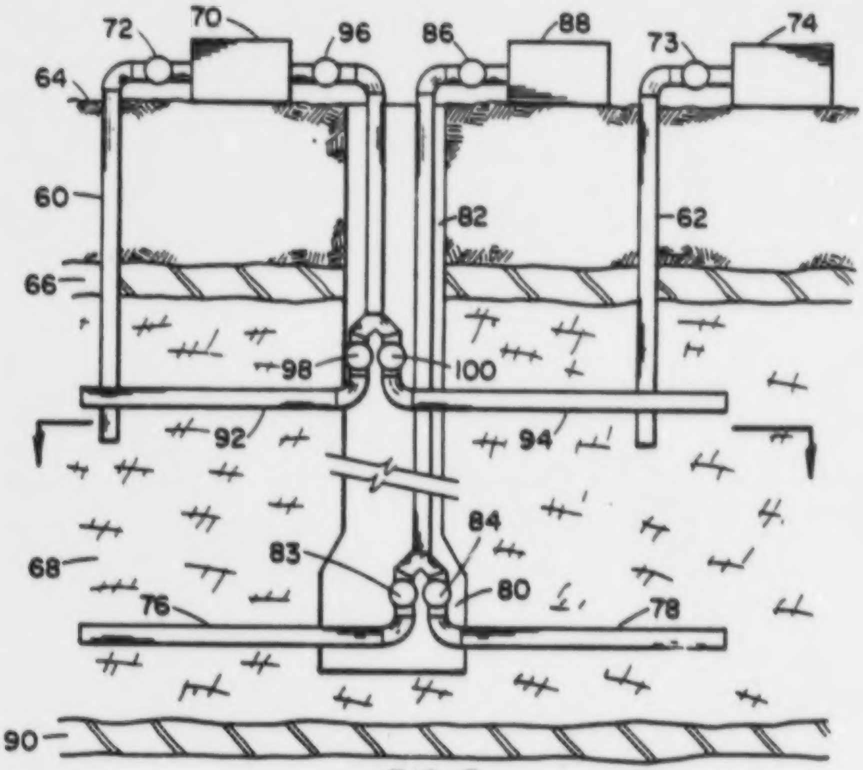

FIG. 5

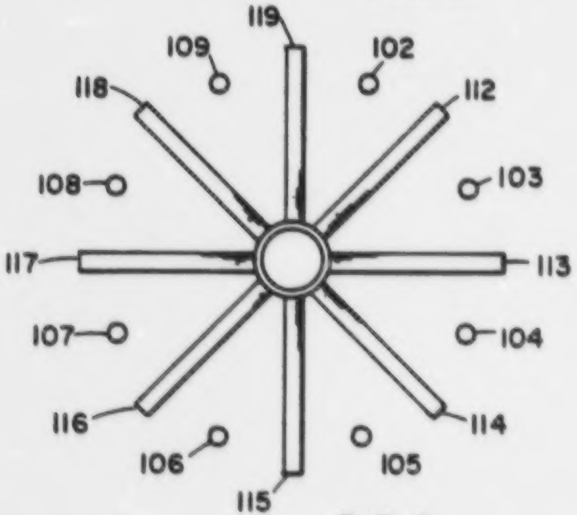

FIG. 6

METHOD FOR RECOVERING HIGH VISCOSITY OILS

RELATED PATENT APPLICATIONS

This is a continuation of application Ser. No. 108,815, filed Dec. 31, 1979, now abandoned, which was a continuation-in-part of Ser. No. 940,390, filed Sept. 7, 1978, now U.S. Pat. No. 4,257,650.

BACKGROUND OF THE INVENTION

This invention relates to methods and apparatus for recovering high viscosity oil from sub-surface earth formations, and more particularly relates to improved methods and apparatus for recovering such oils by employing a large diameter shaft hole and a plurality of drill holes extending radially from the shaft hole.

Early disclosures relating to the recovery of petroleum substances by utilizing a large diameter shaft hole and a plurality of drill holes are provided in U.S. Pat. Nos. 1,520,737 and 1,634,235, and a paper published by Ranney in the *Petroleum Engineer* in 1939 entitled "The World's First Horizontal Hole". These publications propose the drilling of a large diameter shaft into an oil-bearing formation and then drilling radial drill holes into the formation. More recently, U.S. Pat. Nos. 4,020,901; 4,099,570; 4,099,783 and 4,160,481 provide improved systems for recovering petroleum substances employing large diameter shaft holes and radials. The above processes, however, suffer limitations relating to restrictions on the rate of introducing the injection fluid, and the overall efficiency of the oil recovery process according to the above techniques may be so poor that recovery of the oil is not economically feasible.

The publication and patents referred to above teach that steam or other heated fluids can be injected into horizontal drill holes or laterals extending from a large diameter shaft hole. The steam or other heated injection fluid is introduced via laterals into the formation in order to provide heat to the formation and thus reduce viscosity of the oil. The heated oil thereafter flows to recovery laterals, being assisted by gravity.

The above procedure is generally referred to as a "soak" operation, which should be distinguished from a "drive" operation. In a "soak" operation, the injected fluid is intended to lower the viscosity of the oil and thereby enable the oil to more freely flow toward recovery lines by gravitational forces. A soak operation may be enhanced by raising the pressure in the formation and assisting the recovery of oil by increasing the differential between the formation pressure and the pressure at the point of recovery.

It is also common practice to inject fluid into a conventional vertical well for the purpose of driving oil within a formation horizontally to be recovered by a distant vertical well. In this "drive" operation, injected fluid is intended to act as a vertical bank or wall in the formation and push or drive the oil horizontally toward the recovery well. Although the drive operation may be enhanced by injection either a heated fluid or a solvent to additionally lower the viscosity of the oil, the injected fluid is ideally acting as a piston head to move through the formation and drive the oil toward the point of recovery. Horizontal drive often results in viscous fingering and/or gravity override which are very detrimental to a horizontal drive operation. Horizontal drive operations are therefore generally concerned with the "critical velocity" of the injected fluid, so that the driving force does not break down as a result of viscous fingering or gravity override. Since the fluid injected in horizontal drive operations in preferably introduced at rates to keep the driving operation below the critical velocity, the recovery rate, and the corresponding economics of this operation, are often unacceptable. Both phenomena commonly referred to as viscous fingering and gravity override, as well as the differences between "soak" and "drive" operations, are more fully discussed in my co-pending application, Ser. No. 940,390, now U.S. Pat. No. 4,257,650.

It is also well-known to inject water via conventional vertical bore holes into the bottom of an oil-bearing formation, while producing oil from conventional vertical bore holes near the top of the formation. In this procedure, often referred to as conventional vertical flooding, the oil is displaced vertically upward by the injected water. By using conventional vertical bore holes terminating near the top of the formation and conventional vertical bore holes terminating near the bottom of the formation, it is also known that low viscosity oils can be collected by injecting a light hydrocarbon in the top of the formation while recovering the light oil from the vertical bore hole terminating at the bottom of the formation. In the latter procedure, the light oil is pushed downward by the lighter hydrocarbon. The recovery of oil utilizing conventional vertical wells and drive techniques are often poor, however, because a limited number of points of recovery are provided by the vertical wells.

These conventional techniques have several inherent problems. In order to properly "blanket" an area prior to establishing active horizontal driving displacement of the oil, the displacing fluid must be injected at a low rate. Also, if effective blanketing is to be achieved, the formation must have high permeability and the difference in density between the oil and the injected fluid should be high. If a good blanket of injecting fluid is not formed, or if a good blanket is formed but the displacing fluid is injected at too high a rate, viscous fingering can result. When this condition occurs, the injecting fluid no longer effectively displaces the oil, and the volumetric sweep efficiency of the operation falls off drastically.

In order to minimize the likelihood of viscous fingering when utilizing the prior art techniques, the injecting fluid is often introduced into the formation at low injection rates, e.g., 400 barrels of fluid per day per well. Optimum steam injection rates with vertical wells are more fully discussed in an article by Messrs. Bursell and Pittman, appearing in the *Journal of Petroleum Technology*, August, 1975, beginning on page 997. Low injection rates, of course, generally result in low production rates, which significantly increases the cost of production.

The problems and disadvantages of the prior art are overcome with the present invention. Novel methods in apparatus are hereinafter provided for recovering high viscosity oils from sub-surface formations, wherein a greater percentage of the oil can be recovered from the formation and can be recovered in a more efficient manner.

SUMMARY OF THE INVENTION

In one embodiment of this invention, a vertical mine shaft of sufficient diameter to accommodate personnel and equipment is bored to and through a formation containing a high viscosity oil. The vertical shaft is enlarged near the top of the formation and near the bottom of the formation forming chambers to provide increased space for men and equipment. Substantially horizontal drill holes or laterals are thereafter bored radially into the formation. The numbering and spacing of these laterals will be discussed in detail below. For the present, it is significant that one group of laterals is provided near the top of the formation, and another group of laterals is provided near the bottom of the formation. Each group or set of boreholes or laterals effectively blankets a particular portion of the formation, and the configuration of each blanket may be rectangular. Thereafter, drill holes are bored into the face of the formation and radially about the chamber, through which a suitable fluid is thereafter injected into the formation by way of a conduit leading to the surface.

Using the above-described apparatus with one set of laterals near the top of a formation and another set at the bottom of a formation, oil may be recovered by either (a) introducing an injected fluid into the bottom set of laterals while recovering oil from the top set of laterals, or (b) introducing an injected fluid into the top set of laterals while recovering oil from the bottom set of laterals.

The instant invention preferably utilizes a plurality of substantially horizontally laterals which are drilled in the formation for recovery of high viscosity oil through "drive" techniques, while the prior art attempts to improve oil recovery by using boreholes or laterals within the formation and various "soak" techniques. In the present invention, the driving force of the injected fluid is substantially vertical: vertical upward drive toward the top set of laterals, or vertical downward drive toward the bottom set of laterals. The advantage of driving vertically rather than horizontally, as taught by conventional oil recovery techniques, is that the injected fluid may be introduced at a much higher rate because the likelihood of viscous fingering is substantially reduced and detrimental gravity override is eliminated. A fluid may therefore be injected according to the present techniques at rates equivalent to the maximum output of most commercial generators, without regard to the concept of critical velocity, fingering, or gravity override.

In conventional oil wells, it is often quite difficult to establish a blanket of injected fluid, although the fluid is injected at various points in the plane of the blanket. According to the present invention, the blanket of injected fluid may be more easily established since the fluid is not injected at points in the blanket, but rather is injected along entire lines lying within the blanket. These lines effectively provide a multitudinous number of points of injection so that the blanket for the drive operation is more easily established.

As previously mentioned, the apparatus described may be utilized for vertical upward drive or vertical downward drive. This offers a distinct advantage over the prior art since the injected fluid can be selected for either upward or downward drive depending on the density of the oil in the formation, the desirabilty of using a miscible or an immiscible injected fluid, the availability of the injected fluid, and the particular characteristics of the formation. For instance, if the oil in the formation is a heavy crude oil, e.g. 14° API, and a relatively heavy injected fluid is available, e.g. carbon disulfide, vertical upward drive of the oil is feasible. Thus, carbon disulfide, may be injected in the bottom set of laterals, and since the injected fluid is heavier than the oil, it would not tend to rise naturally in the formation. A blanket of injected fluid may be thereby easily established in the bottom of the formation. As the injection of carbon disulfide continues, the injected fluid drives oil upward in the formation toward the top set of laterals. Fluid may continue to be injected in the bottom set of laterals while oil is recovered from the top set of laterals, until the injected fluid is effectively driven through the entire formation.

If, on the other hand, the formation pressure is high and heated water is readily available as an injected fluid, downward vertical drive may be desirable heated water at 500° F. is less dense than 14° API oil. Thus, heated water may be injected in the top set of laterals serving to drive the oil downward for recovery by the bottom set of laterals. In this manner, a blanket of injected fluid is established in the upper portion of the formation, and the oil is driven downward by the continued injection of fluid.

The particular spacing and arrangement of drill holes will, of course, depend upon the size and lithology of the formation of interest, but it is a feature of the invention to provide approximately eight different radially extending drill holes for each shaft hole, and to further extend such drill holes to a location adjacent the ends of similar radicals extending from an adjacent vertical shaft hole. As will hereinafter be explained in detail, each group of radial drill holes will then define a rectangular pattern within the field, and thus the field may be effectively "covered" with a blanket of such rectangular patterns.

The bore holes or radicals may extend from the large diameter shaft hole in a generally horizontal direction. Some of the radials, however, may be positioned at a slight upward angle, e.g., 3°-7°, so that gravity may assist the flow of oil within the lateral. Also, some formations have generally horizontal barrier zones which are impermeable to fluid flow. Relatively thin shale deposits are one example of these impermeable barrier zones. When such zones exist, the bore holes or laterals may be drilled at a greater upward angle, e.g., 10°-18° upward from the horizontal, so that the bore holes would pass through one or more of these barrier zones. Thus, the recovery of oil and the efficiency of the operation will be increased since oil can be recovered by soak or drive techniques which would have previously remained within the formation because of the presence of the impermeable barrier zones.

It is within the concept of the present invention to locate the radials adjacent the lower limit of the formation, whereby the fluid injected therefrom will also tend to rise as well as travel laterally through the formation, and also to provide additional pluralities of such radial drill holes at other higher locations within thicker formations. Furthermore, it is within the concept of this invention to inject fluid through only a portion of the radials, while also recovering oil from one or more of the other radials extending from the same shaft hole.

The invention is suitable for recovering oil from subsurface formations, and is particularly suitable for recovering high viscosity oils. High viscosity oils are generally inclusive of both medium gravity oils having an API range of 20° to 25°, and heavy crude oils having an API range of 20° or less.

A particular feature of this invention is to provide methods and apparatus that result in increased production rates for recovering high viscosity oil from subsurface earth formations.

It is another feature of this invention to provide methods and apparatus for driving oil within a subsurface earth formation vertically toward recovery laterals extending radially from a large diameter shaft hole.

It is a further feature of this invention to provide methods and apparatus that will increase the overall efficiency of recovering high viscosity oil from a subsurface earth formation by utilizing vertical drive techniques.

It is an additional feature of this invention to provide apparatus for recovering oil from a subsurface earth formation, comprising a shaft hole extending from the surface to said subsurface earth formation, a first plurality of boreholes extending radially from said shaft hole into said formation at a first elevation, a second plurality of boreholes extending into said formation at a second elevation, and injection means introducing a fluid through said second plurality of said boreholes and into said formation for driving said oil vertically for recovery by said first plurality of boreholes.

It is a further feature of this invention to provide a method of recovering oil from a subsurface earth formation, comprising establishing a shaft hole extending from the surface of the earth to said subsurface earth formation, drilling a first plurality of boreholes radially from said shaft hole into said formation at a first elevation, drilling a second plurality of boreholes into said formation at a second elevation, and injecting a driving fluid into said second plurality of boreholes and into said formation for driving said oil vertically for recovery by said first plurality of boreholes.

These and other features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

IN THE DRAWINGS

FIG. 1 is a simplified pictorial representation, partly in cross section, of an exemplary installation for recovering oil from a subsurface earth formation according to the present invention.

FIG. 2 is a cross-sectional representation of a portion of the apparatus depicted in FIG. 1.

FIG. 3 is a simplified pictorial representation, partly in cross section, of a portion of the apparatus depicted in FIG. 1.

FIG. 4 is a graph illustrative of the variations in specific gravity for fluids, and is referred to in the description to assist in illustrating the concepts of the present invention.

FIG. 5 is a simplified pictorial representation, partly in cross section, of another form of an exemplary installation according to the present invention.

FIG. 6 is a cross-sectional representation of a portion of the apparatus depicted in FIG. 5.

DETAILED DESCRIPTION

In FIG. 1, there may be seen a pictorial representation of an oil recovery system embodying the concepts of the present invention. In particular, the apparatus depicted in FIG. 1 may be utilized for recovering high viscosity oil from subsurface earth formations. A substantially vertical mine shaft 2 is drilled or bored from the surface 4 to the oil bearing formation 6. The oil bearing formation 6 may typically be hundreds of feet below the surface 4, and is shown to be bounded by an

upper layer 5 and a lower layer 7 of shale deposits, which are generally impregnable to fluid flow. As seen in FIG. 1, the mine shaft 2 is drilled through the oil bearing formation 6, and terminates at a sump hole 8.

The shaft 2 is expanded near the top portion of the formation to form an upper work chamber 10, and is expanded at the bottom portion of the formation to form a lower work chamber 12. A plurality of upper laterals 14 and 16 may be drilled into the formation 6 from the upper work chamber; a plurality of lower laterals 18 and 20 may likewise be drilled into the formation from the lower work chamber 12.

A steam generator 22 at the surface floor provides injection fluid to the upper laterals 14 and 16 by a steam line 24. If desired, a plurality of steam lines 24 may be provided, so that the injected fluid to each upper lateral may be separately controlled at the surface by conventional valving techniques. The lower laterals 18 and 20 may serve as recovery lines for oil, which is collected in recovery tank 26. Each of the lower laterals 18 and 20 may be connected to individual recovery lines 28 and 30 which may terminate at the recovery tank 26, or the recovery lines 28 and 30 may join at a subsurface manifold 32 so that oil from the various lower laterals 18 and 20 flows to the recovery tank 26 by a central recovery line 34.

Referring again to FIG. 1, it may be seen that a portion of the radial or lateral 14 extending from the wall of the upper work chamber 10 may be suitably provided with a casing 36, with a perforated portion of the lateral 14 thereafter extending from the casing 36. The walls of the shaft 2 may be conveniently sealed with sections of bolted or welded steel plates to form a casing 38, or may be lined with an appropriate material such as gunite, to prevent caving or other collapse of the walls of the shaft 2. The diameter of the shaft 2 is preferably of a size sufficient to accommodate the passage of men and equipment from the surface 4 to the interior of the work chambers 10 and 12. The mine shaft 2 and each of the work chambers 10 and 12 may be constructed in the manner further described in U.S. Pat. No. 4,160,481.

In the embodiment of this invention illustrated in FIG. 1, fluid is injected into the formation via radial drill holes or laterals 14 and 16 which lie entirely within the formation 6. If the injected fluid is heated water or steam, heat loss by way of the steel casing 38 therein is not significant since the heat merely transfers to the formation. On the other hand, it is desirable for the injected fluid to enter the formation at a distance from the shaft 2 or work chamber 10, so that the fluid will tend to move outwardly therefrom instead of bypassing back into the chamber 10. Furthermore, it may be preferable to insert pre-perforated pipe or casing into the radial drill holes, rather than to perforate the casing in a conventional manner after it has been inserted. The upper laterals may contain the casing 36, but the casing is not necessary according to the present invention. Thus, although the casing 36 is only shown for the upper lateral 14, it is within the concept of my invention that the casing be employed with all, some, or none of the injection laterals.

Referring now to FIG. 2, there is illustrated a cross-sectional view of the laterals shown in FIG. 1. In FIG. 2, four upper laterals radiate from the shaft 2 at 90° intervals, and are denoted as 14, 15, 16 and 17. Four lower laterals are also spaced at 90° intervals, and the lower laterals 18, 19, 20, and 21 are shown connected to their respective vertical recovery lines 28, 29, 30, and 31.

Both the upper set of laterals and the lower set of laterals depicted in FIGS. 1 and 2 lie in substantially horizontal planes. As explained in further detail below, the upper set of laterals, in combination with an injected fluid, form a blanket of injected fluid which act as the driving force for the recovery process. Typically, the laterals will radiate from the shaft 2 to enable a substantially horizontal blanket to be established having an area of 25 acres. In FIG. 2, the pattern of the blanket formed by the injection radials 14, 15, 16, and 17 is circular. Other configurations are possible, and the particular configuration of the blanket formed by the injection laterals will depend, in part, on the characteristics of the formation, the viscosity of the oil in the formation, the injected fluid, and the possible use of injection laterals in combination with conventional wells. For instance, the configuration of the injection laterals may form a rectangular blanket, as shown in my co-pending patent application, which is hereby incorporated by reference in its entirety. The length of the laterals will depend on their relative position to one another, since the injection laterals preferably function to form a uniform substantially horizontal blanket in a portion of formation 6. Further, the diameters of the laterals will depend primarily upon the type of matrix composing the formation 6, as well as the viscosity of the oil sought to be recovered therefrom.

FIG. 3 illustrates a portion of the apparatus generally depicted in FIG. 1. A tubular member 40 is typically inserted into any of the boreholes described, such as the laterals 14, 15, 16, and 17 in FIG. 2. Likewise, a tubular member 42 may be inserted into the laterals 18, 19, 20, and 21. The oil bearing formation 44 is bounded on the top by a layer of shale or other rock 46, and on the bottom by a similar impregnable layer of shale or other rock 48. The layers 46 and 48 are typical of any number of materials which often exist on the upper and lower portions of an oil bearing formation. Generally, these impregnable layers line a substantially horizontal plane, although perhaps not as uniform as the layers depicted.

As previously stated, it is preferable according to the present invention that the upper tubular member 40 be placed near the upper portion of the formation, and that the lower tubular member 42 be near the bottom portion of the formation. The exact spacing of the upper and lower laterals will possibly depend on the configuration of the layers 46 and 48. If these layers are uniform and substantially horizontal within the area of the recovery operation, the laterals may be drilled very close to the layers. If the layers are irregular in configuration, the upper laterals may be drilled in the upper fifth of the formation, and the lower laterals in the lower fifth of the formation. For example, if the formation 44 is approximately 60 feet thick and substantially uniform in configuration, the upper tubular member 40 is preferably 1 to 5 feet from the bottom of the top layer 46, and the lower tubular member 42 is preferably 1 to 5 feet above the top of the bottom layer 48.

A simplified method of operation according to the present invention will now be described by reference to FIGS. 1, 2, and 3. For the present, it will be assumed that steam has been selected as the injection fluid, and that both steam and water at the temperature and pressure within the formation are less dense than the oil in the formation.

Steam from the generator 22 may be injected into upper laterals 14, 15, 16, and 17 by a plurality of steam lines 24. The steam may enter the formation 44 through a series of perforations in the upper tubular members, such as the perforations 50 in the tubular member 40. The perforations 50 may be formed along the entire length of the tubular member 40, and are preferably formed along at least a substantial portion of the length of the tubular members.

Heat from the injected steam will decrease the viscosity of the oil in the formation adjacent the tubular member 40. As the formation 44 is heated, condensate may be formed which will be more dense than the steam, but less dense than the oil in the formation. The steam from the tubular member 40 will, in combination with the steam simultaneously injected in the other upper laterals, produce a blanket of steam generally in the plane of the upper laterals.

Continued injection of steam into the upper laterals will cause a pressure increase in the top of the formation 44. This pressure increase will drive the oil in the formation downward toward the lower tubular member 42. Also, the condensate from the injected steam may serve as a face for the driving force. In other words, the increase in pressure above the condensate layer will force the condensate layer downward, thus driving the oil downward from the formation.

As the steam is injected in the upper tubular member 40, oil will be simulataneously recovered through perforations 54 along a substantial portion of the length of the lower tubular member 42. Referring to FIG. 2, steam injected into the upper laterals 14, 15, 16, and 17 will drive the oil downward for recovery by the lower laterals 18, 19, 20, and 21. In this manner, the oil from the formation 44 may be efficiently recovered by the downward drive of the injection fluid.

As stated above, the present invention may be effectively employed by utilizing a driving fluid and driving the oil vertically toward recovery laterals. In a vertical driving technique, the pressure gradient within the formation may be altered by the injected fluid to force the oil toward the recovery lines. Because of the weight of the oil in the formation, the pressure near the upper section of the formation will generally be less than the pressure in the lower portion of the formation. By way of illustration and referring to FIG. 1, if the formation 6 were 60 feet thick and the pressure at the top of the formation just below the layer 5 was 15 psi, the pressure near the bottom of the formation above the layer 7 may typically be 40 psi because of the pressure gradient of the oil in the formation 6.

According to the vertical steam drive techniques discussed herein, drawing the oil from the recovery lines and injecting a fluid into the injection lines will produce a pressure differential sufficient to force or drive the oil vertically. Preferably, a pressure differential of 100 psi or more is achieved during the driving process between the pressure at the place of injection and the pressure at the place of recovery within the formation. The preferred pressure differential will vary depending on the specific characteristics of the oil and the formation, and typically a pressure differential of 200 psi to 400 psi will be desired. The maximum pressure at the place of injection is generally limited for safety reasons to 1 psig per foot of overburden. For instance, if steam is injected into the laterals 14, 15, 16 and 17 which are 400 feet below the surface 4, it may be desired to limit the pressure provided in the upper portion of the formation 6 to 400 psi.

As previously mentioned, vertical drive may be properly utilized without concern for gravity override, even with injection rates far exceeding the injection rate employed in conventional horizontal drive. In the embodiment described above, the density contrast between the oil and the injected fluid is deliberately utilized during the driving operation to increase the efficiency of the recovery processes, while the same density contrast may result in gravity override in horizontal drive operations which is detrimental to the efficiency of horizontal drive recovery processes. Also, since the oil is being driven vertically downward, the likelihood of viscous fingering during the driving operation is substantially eliminated since (a) a uniform blanket of driving fluid is initially formed, (b) the condensate layer 52 acts as a face for driving the oil from the formation, and (c) the oil is being driven vertically downward, and the injected fluid will not tend to pierce through the formation 44 because the injected fluid is less dense than the oil below the injected fluid. Further, as explained below, viscous fingering prior to the driving operation increases the efficiency of the recovery process according to the present invention, rather than being detrimental to the recovery efficiency as in horizontal drive techniques.

Steam may be continually injected into the upper tubular member 40 until condensate or steam has been recovered from the lower tubular member 42. At this point, further injection of steam may be economical, since little if any further oil will be recovered from the lower tubular member 42. If the vertical recovery lines 28 and 30 are used to connect each lateral to the recovery tank 26, it is possible to monitor the fluid being recovered at the surface 4 from each lower lateral. In this manner, it may be desirable to discontinue the injection of steam into the upper laterals which are adjacent the lower laterals in which steam or condensate is being recovered, while continuing to inject steam into the other upper laterals as long as oil is being produced from their respective adjacent lower laterals. If the recovered oil is either being forwarded to a subsurface manifold 32 or is being taken from a common sump hole 8, the monitoring of the recovered fluid from the individual lower laterals may be accomplished before that fluid is intermingled with fluid from the other lower laterals. Use of the common sump hole 8 for recovering laterals is more fully described in my co-pending application Ser. No. 940,390.

Referring again to FIG. 2, the following is an example of the monitoring procedure described above. Steam may be initailly injected into the four laterals 14, 15, 16, and 17, forming a substantially horizontal blanket of steam in the plane of the upper laterals. Continued injection of the steam will drive the oil in the formation to the lower laterals. Once steam or condensate has been recovered from one of the lower laterals, e.g., lateral 21, steam may be continued to be injected into the upper laterals 15 and 16, while steam is not injected into the upper laterals 14 and 17. Thus, oil recovery would continue from the lower laterals 18, 19, and 20, but oil recovery from the lower lateral 21 would be effectively discontinued.

An alternative procedure that may be used when steam or condensate is recovered in one of the plurality of lower laterals is to inject cold water into the lower lateral while continuing steam injection into the upper laterals. Referring to the example described immediately above, if water or condensate is being recovered from the lower lateral 21, cold water may be injected into lower lateral 21 while continuing to inject steam in either upper laterals 15 and 16 or all the upper laterals 14, 15, 16, and 17. The introduction of the cold water into the lower lateral 21 effectively terminates the recovery of any fluid from the lateral 21, thus the steam injected into the formation would be effectively used to produce oil from the laterals 18, 19, and 20.

One of the advantages of the plurality of upper laterals 14, 15, 16, and 17 is that a blanket can be easily and rapidly established in the formation which will enhance the driving efficiency of the injected fluid. The rapid establishment of a blanket in the formation will increase the thermal efficiency of the recovery process since less heat and injection fluid will be lost to adjacent beds or escape from the formation entirely. Conventional vertical injection wells do not result in the rapid and efficient establishment of a blanket, since the fluid is injected at points within the plane of the blanket. According to the present invention, the laterals lie within the plane of the blanket to be established, and thus lines of injection are provided rather than mere points of injection. The particular number of laterals used will depend on a variety of factors. It is within the concept of the present invention that a plurality of laterals radiate from the mine shaft at at least two vertical elevations. The embodiment illustrated in FIG. 2 shows four upper laterals and four lower laterals, but any number of upper and lower laterals may be used. For instance, eight equally spaced upper laterals could be used in conjunction with eight equally spaced lower laterals. The efficiency of the recovery process would be generally enhanced by the increased number of laterals, but the increased number of laterals also results in increased drilling and equipment costs.

It is preferable that equal numbers of upper laterals and lower laterals be provided, and that the individual upper laterals and individual lower laterals be equally spaced from each other. Thus, as shown in FIG. 2, each of the upper laterals is 90° apart from adjacent upper laterals, and the lower laterals are 90° apart from adjacent lower laterals. In addition, it is preferable that lower laterals be spaced between upper laterals, as compared to having the lower laterals directly below the upper laterals. As shown in FIG. 2, each of the lower laterals is 45° apart in the horizontal direction from its adjacent upper laterals; if eight upper laterals were used in conjunction with eight lower laterals, each lower lateral would preferably be offset from its adjacent upper lateral by 22.5°. One advantage in offsetting the lower laterals from the upper laterals is that a longer path is thereby provided between the injection laterals and the recovery laterals. Thus, the injection fluid tends to spread out evenly through the formation and increase the sweep efficiency of the recovery process. If the upper laterals were to be placed directly above the lower laterals, there is less likelihood that the oil near the bottom of the formation and between the lower laterals would be recovered.

As previously described, the use of upper and lower laterals within a formation enables a blanket to be easily formed for the driving process. It is possible to use conventional vertical injection wells instead of the injection laterals, although the blanket of driving fluid may not be established as readily as if horizontal boreholes or laterals were used for the injectors. Referring to FIG. 5, there is illustrated another form of my invention which employs the use of conventional vertical wells 60 and 62. It will be seen that these conventional vertical wells 60 and 62 are drilled from the surface 64 through the top rock layer 66 and terminate in the upper portion of the formation 68. Fluid may be injected into the vertical wells from a common generator, or separate generators 70 and 74 may be employed for each vertical well. Valves 72 and 73 may be used to control the flow of fluid from the generators to the formation.

The laterals 76 and 78 extend radially from the work chamber 80 in the lower portion of the mine shaft 82. The lower set of laterals preferably "blanket" a portion of the formation, as previously described. Valves 83, 84 and 86 may be used to control the recovery of oil from the laterals to the recovery tank 88. In FIG. 5, both the laterals 76 and 78, and the work chamber 80 are entirely within the lower portion of the formation 88, and lie above the rock layer 90.

It is also within the concept of my invention to utilize conventional vertical boreholes in combination with both upper and lower laterals, if desired, to assist the formation of a blanket and the driving process. Thus, in FIG. 5 there is illustrated vertical injection wells 60 and 62 plus horizontal laterals 92 and 94. By controlling valves 96, 98 and 100, the injection of fluid from the generator 70 to each of the horizontal injection laterals 92 and 94 may be controlled.

Referring now to FIG. 6, there is shown a cross-sectional view of a portion of the apparatus depicted in FIG. 5. The vertical injection wells are designed as 102, 103, 104, 105, 106, 107, 108 and 109, with wells 103 and 108 corresponding to the wells 60 and 62 shown in FIG. 5. The horizontal recovery laterals form a generally rectangular blanket, and are designated as laterals 112, 113, 114, 115, 116, 117, 118 and 119, with laterals 113 and 117 corresponding to laterals 76 and 78 in FIG. 5. It will be seen that the vertical wells may be spaced between the horizontal laterals, and that the injection wells are spaced geographically to cover the area to be blanketed. If desired, other injection wells may be spaced inwardly to the vertical mine shaft from the injection wells shown in FIG. 6.

If horizontal injection laterals are utilized, it is anticipated that vertical injection wells would generally not be necessary. On the other hand, if vertical injection wells are utilized, it generally may not be necessary to drill horizontal injection laterals. However, it is possible to use both vertical and horizontal injections, and this may be desirable if only a relatively few number of injection laterals are utilized.

To assist in establishing a horizontal blanket if vertical injectors are used in combination with recovery laterals, fluid may be initially injected into a portion of the vertical boreholes while oil is recovered from the remaining vertical boreholes. Thus, fluid may initially be inserted into the odd-numbered vertical wells, and the oil may be driven horizontally and recovered by the adjacent even-numbered vertical boreholes until the injection fluid is recovered in the adjacent even-numbered vertical boreholes. At this point, a horizontal blanket of injection fluid is established, and fluid may be injected in all the vertical boreholes 102 through 109 to drive the oil downward for recovery by the lower laterals 112 through 119. In this embodiment, the vertical boreholes are preferably spaced between the injection laterals and toward the periphery of the blanketed zone to increase the efficiency of the recovery operation. As previously described, it is within the concept of this invention to drive vertically upward or vertically downward, and the conventional vertical boreholes herein described may terminate near the top of the formation if downward drive is desired, or may terminate near the bottom of the formation if upward drive is desired.

It is within the concept of this invention to employ a plurality of substantially horizontal laterals and inject fluid to drive the oil in the formation vertically toward recovery laterals. Oil may be driven vertically upward or downward, and thus the upper laterals and lower laterals may function either as injection laterals or recovery laterals. For instance, steam may be effectively used in many operations wherein the steam is injected into the upper laterals, since both the steam and the condensate at the temperature and pressure within the formation may be less dense than the oil. However, some miscible fluids which are more dense than the oil in the formation can also be effectively used as a driving fluid. If the injected fluid chosen, e.g., carbon disulfide, is more dense than the oil, it may be advantageous to inject the fluid in the lower laterals 18, 19, 20, and 21 while recovering oil from the upper laterals 14, 15, 16, and 17. In this case, the heavier injected fluid would easily and rapidly form a blanket in the lower portion of a formation, and continued injection would drive the oil upward toward the recovery laterals. Also, neither gravity override or viscous fingering is a problem in this case during the driving operation, since the heavier injected fluid is below the oil to be displaced.

It may therefore be seen that the present invention is applicable with both miscible and immiscible injection fluids. Also, it is within the concept of my invention to inject a liquid lighter than the oil in a formation into the upper laterals, and thereafter to drive the oil downward toward the lower laterals by injecting a gas or a gas/liquid mixture in the upper laterals as the driving force. More particularly, a solvent less dense than the oil may be injected into the upper laterals to form a blanket of fluid to act as the face of the driving force. Successively lighter slugs of fluid, each slug having a lower density than the previous slug, may thereafter be injected into the formation. Finally, a gas may be injected. The injecting slugs of fluid and gas produce a driving force, and the solvent first injected acts as the face of the driving force. This technique, which may be referred to as graded miscible displacement, may be highly effective, permit much higher injection rates, and yield higher production rates than possible according to the prior art.

The density of the injection fluid may vary with temperature changes to a different extent than the oil in the formation. It is possible, therefore, to inject a particular fluid in the top laterals as a driving force when that fluid is lighter than the oil, and to inject the same fluid in the lower laterals as a driving force when the fluid is heavier than the oil in the formation. Referring now to FIG. 4, there is depicted a chart which illustrates the approximate density of the water, 10° API oil, 12° API oil, and 14° API oil as a function of temperature. It will be noted that at 100° F., water is denser than 12° API oil, but that at 500° F., 12° API oil is denser than water.

The principle of different density changes for fluids can be fully utilized according to the present invention. For example, high temperature steam can be injected into the upper laterals, and 12° API oil can be recovered by the lower laterals. At the pressure within the formation, the condensate from the high temperature steam may form a layer of water at 500° F. In this case, both the steam and the condensate are lighter than the oil, and can be efficiently used to drive the oil downward. After steam or condensate has been recovered from one of the lower laterals, the injection of steam may be continued in the upper laterals that are not adjacent the lower lateral from which the condensate was recovered, as previously described. (Alternatively, steam may be injected in all the upper laterals while cold water is injected in the lower lateral from which condensate or steam has been recovered). If the formation were at a relatively shallow depth and therefore correspondingly lower formation pressures existed, it is within the concept of my invention to inject superheated steam to achieve the high temperature desired to maximize the efficiency of the recovery process.

After the downward steam drive has been completed, the driving process may be reversed and cold water may be injected in the lower laterals while oil is recovered from the upper laterals. From the graph in FIG. 4, it may be seen that at a temperature of 100° F., water is more dense than 12° API oil, and thus the injection of water will now drive some of the remaining oil in the formation upward toward the upper laterals. Thus, during both the vertically upward driving stage and the vertically downward driving stage, the density of the injected fluid enables an effective blanket to be established, and the likelihood of viscous fingering is substantially eliminated.

Although driving vertically in one direction according to the present invention will effectively sweep the formation, it is understood that the oil recovery process will not be 100% effective. Driving in both directions, i.e., driving downward and thereafter driving upward, will increase the percent of oil recovered. This increased recovery is due, in part, to the fact that formations are not completely homogeneous, and thus driving in the reverse direction will cause the driving fluid to invade some areas that may have been sheltered from the forward driving fluid. Also, the injection of cold water in the lower laterals, as described above, may cause some water to flash to steam because of the residual heat in the formation, and the steam may lower the viscosity of some remaining oil to enhance the effectiveness of the upward driving process.

In the methods described above, oil recovery is based on a vertical drive process, which may be simplictically described as injecting the fluid in one set of boreholes while recovering oil from another set of laterals. It is within the concept of my invention, however, to improve the efficiency of the vertical driving process by providing for a limited soak cycle for each of the sets of laterals. For instance, if a vertical downward drive of the oil is to be achieved, it may be initially desirable to inject steam in the lower laterals to soak the formation directly adjacent the lower laterals and thus improve the subsequent driving process. Also, the upper laterals may be thereafter injected with steam to soak the formation adjacent the upper laterals and therefore enhance the uniformity of the driving blanket. After the lower laterals have been opened and oil begins to flow in the lower laterals, steam may thereafter be injected in the upper laterals to drive the oil toward the lower laterals.

Soaking the formation about the upper and lower laterals prior to establishing the driving process, as described above, may be beneficial in most applications. If a high viscosity oil is to be efficiently driven, it may be desirable, if not essential, to establish a flow path between the point of injection and the point of recovery prior to the driving cycle. The heavy oil in many formations has such a high viscosity that it is very difficult to displace the oil by an injection fluid supplied from commercial generators.

If steam is to be used as the injection fluid in the application depicted in FIG. 1, the efficiency of the downward driving process may be substantially increased by first injecting steam in the lower set of laterals 18, 19, 20 and 21. As the lower portion of the formation 6 is being soaked, viscous fingering and gravity override will readily occur since the injected fluid is lighter than the oil, and is being introduced in the lower portion of the formation. As viscous fingering and gravity override occur, heated communication paths will be established between the lower set of laterals and the upper set of laterals. Thus, the formation may be subjected to repeated steam soak cycles from steam supplied through the lower set of laterals, wherein steam is injected into the lower laterals, the laterals are stopped off or shut in, and the laterals are opened for recovery of oil as a result of the soaking process.

When the repeated soaking from the lower laterals results in steam fingering to the top of the formation 6, the soaking process may discontinued and steam thereafter injected into the upper set of laterals 14, 15, 16 and 17 for driving the oil downward while recovering oil from the lower set of laterals. The steam soak cycle therefore results in communication paths between the injection locations and the production locations which may have a greater area than that commonly associated with horizontal driving techniques. For instance, when conventional horizontal drive between vertical wells is utilized in a formation 60 feet thick, the area or face of the driving formation is typically approximately 12,500 square feet per acre. If vertical drive is practiced between horizontal laterals according to the present invention, the area or face of the driving front increases to approximately 43,000 square feet per acre. Thus, if the same injection rate per area of driving front is utilized, fluid is injected at approximately 3.5 times the rate as in conventional horizontal drive. Moreover, since the oil is being driven vertically rather than horizontally, the injection rate per area of the driving front may be substantially increased since viscous fingering is substantially eliminated during the driving operation.

The larger driving face area, therefore, enables more driving fluid to be injected into the formation while maintaining a relatively low, stable driving velocity across the formation. Also, as previously mentioned, the driving velocity may be substantially increased when compared to horizontal drive since vertical driving minimizes the likelihood of viscous fingering. Further, the fluid may be injected at higher pressures and at higher rates than realized in the prior art, which improves the efficiency of the recovery process. For instance, steam which may have been injected at 25% quality in horizontal drive operations may effectively be injected at the higher rates and with greater steam quality, e.g., 80%, than in the prior art. Also, as previously mentioned, superheated steam may be used as the injection fluid.

Although this invention has principally been described with steam or water as the injection fluid, both heated and unheated fluid may be used as a driving force within the concept of my invention. For example, water, solvents, gas oil, distillate, LPG, and naptha, or a combination of liquids and gases may be utilized as the driving fluid according to the present invention. Examples of gases that may be used in this invention are air, oxygen, hydrogen, carbon dioxide, inert gas, stack gas, steam, anhydrous ammonia, natural gas, ethane, propane and butane. Also, although no additives must be combined with the fluid to be injected, the addition of additives may enhance the recovery process. Less heat is lost through condensation, and the average temperature of the formation is raised at a faster rate than in the prior art. Thus, the increased injection rates yield higher production rates, which improve the economics of the recovery operation.

It is also within the concept of this invention to utilize in situ combustion to achieve or enhance vertical drive of the oil toward horizontal recovery laterals. For instance, if horizontal laterals are placed near the bottom of the formation, in situ combustion near the top of the formation will tend to drive the oil downward. Air or oxygen for the combustion process may be injected via either conventional vertical injection wells from the surface to the upper portion of the formation or horizontal laterals from the mine shaft. Referring to FIGS. 5 and 6, if desired air or oxygen may be injected via the odd-numbered vertical wells, and in situ combustion used to recover oil from the even-numbered vertical wells as the combustion process drives the oil in the upper portion of the formation horizontally. After in situ combustion has progressed in a horizontal direction and the producing even-numbered vertical wells become heated, all the conventional vertical wells 102 through 109 may be used to inject air or oxygen. Thus, in situ combustion may thereafter be utilized to drive the oil downward for recovery by the laterals or boreholes 112 through 119. If desired, this latter operation may be conducted in rotating segments, rather than exploiting the entire area at one time, which would reduce the capital investment required for the air or oxygen compressors.

Alternatively, in situ combustion may be conducted in the upper portion of the formation between conventional vertical wells, as previously described, and thereafter another fluid such as water, steam, inert gas or mixtures thereof injected into all the vertical wells for driving the oil downward for recovery by the horizontal laterals. If desired, the lower horizontal laterals may be initially steam soaked or soaked at intervals during the driving process to maintain the desired recovery flow. The in situ combustion between the conventional vertical wells may be conducted until enough heat has been added to the formation for an efficient oil recovery by subsequent vertical drive techniques. If water is injected into the formation as the driving fluid from the vertical conventional wells, the residual heat from the "burned out" zones may generate steam in situ which may efficiently drive the remaining oil downward for recovery by the laterals.

The above operation is especially attractive from an economic standpoint since little or no surface fuel is used to heat the formation. Temperatures in the combustion zone may be 800° F. to 1000° F. or more, and very good drive of heavy oil can be achieved if the oil in the formation is heated to 250° to 300° F. Also, creating a blanket of combustion-cleaned matrix establishes extremely high vertical downward transmissibility for the injected fluids used in the subsequent driving cycle.

In situ combustion further dehydrates and breaks down any shale layers or lenses within the combustion zone.

The recovery of oil when utilizing vertical drive, as described according to my invention, may be further enhanced by reducing the pressure at the recovery laterals to a sub-atmospheric value by connecting the recovery laterals to suction-type pumps. In this manner, oil recovery may be enhanced regardless of whether the vertical drive is propagated by in situ combustion, steam injection, solvent injection, gas injection, or injection of any number of fluids commonly used to enhance the driving operation.

The injection laterals in the embodiments described are preferably positioned in a substantially horizontal plane. The laterals may be inclined to conform to the inclination of the barrier layer, but the injection laterals with the injected fluid principally serve to establish a uniform, substantially horizontal blanket to be driven vertically through the formation. The recovery laterals are generally positioned in a similar substantially horizontal plane so that the formation may be efficiently swept of oil. Some deviation of the laterals is expected, and in that sense the upper and lower laterals may not lie precisely in flat planes. Further, the laterals typically lie in relatively thin discs approximately five feet thick, and these discs or "planes" may be inclined slightly to conform to the barrier layers.

It may also be seen that the present invention may be profitably employed by installing a plurality of vertical mine shafts and laterals, as described herein. Also, by operating such multiple installations in a simultaneous manner, as more fully described in my co-pending patent application, Ser. No. 940,390, an entire field may be drained in a systematic manner.

It may be that two or more oil bearing formations exist at different elevations. In such a case, it is within the concept of my invention that a vertical mine shaft may be employed, and upper and lower laterals may extend from the mine shaft into each of the oil bearing formations.

As hereinbefore described, the techniques of the present invention are principally directed to recovery of relatively heavy oils. However, it should be noted that these techniques are not limited to heavy oils only, but can be used with substantial affect in recovering hydrocarbons of various weights and gravities.

Other alternate forms of the present invention will suggest themselves from a consideration of the apparatus and practices hereinbefore discussed. Accordingly, it should be clearly understood that the systems and techniques depicted in the accompanying drawings, and described in the foregoing explanation, are intended as exemplary embodiments of my invention, and not as limitations thereto.

What I claim is:

1. A method of recovering oil from a subsurface earth formation, comprising:

establishing a shaft of oil extending from the surface to said subsurface earth formation;

drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane within an upper portion of said formation;

drilling a second plurality of boreholes radially from said shaft hole in another substantially horizontal plane within a lower portion of said formation;

introducing a displacing fluid through one of said plurality of boreholes and into said formation for forming a substantially horizontal blanket of displacing fluid;

injecting a driving fluid through said one of said plurality of boreholes and into said formation along at least a substantial portion of each of said one of said plurality of boreholes for vertically driving said displacing fluid through said formation;

withdrawing oil from the other of said plurality of boreholes while injecting said driving fluid into said formation;

monitoring recovery of said driving fluid from each of said other of said plurality of boreholes, and

injecting a liquid comprising substantially water through selected ones of said other of said plurality of boreholes in response to recovery of said driving fluid from each of said other of said plurality of boreholes for inhibiting further recovery of said driving fluid.

2. A method as defined in claim 1, further comprising:

thereafter injecting another driving fluid through said other of said plurality of boreholes for driving said oil vertically toward said one of said plurality of boreholes; and

recovering oil from said one of said plurality of boreholes while injecting said another driving fluid into said formation.

3. A method of recovering oil from a subsurface earth formation, comprising:

establishing a shaft hole extending from the surface to said subsurface earth formation;

drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane within an upper portion of said formation;

drilling a second plurality of boreholes radially from said shaft hole in another substantially horizontal plane within a lower portion of said formation;

simultaneously introducing a displacing fluid comprising substantially steam through each of said first plurality of boreholes and into said formation for forming a substantially horizontal blanket of displacing fluid;

subsequently injecting a driving fluid through each of said first plurality of boreholes and into said formation along at least a substantial portion of each of said first plurality of boreholes for vertically driving said displacing fluid through said formation; and

withdrawing oil from said second plurality of boreholes while injecting said driving fluid into said formation.

4. A method as defined in claim 3, wherein said driving fluid comprises substantially a non-condensible gas.

5. A method as defined in claim 3, wherein injecting said driving fluid further comprises:

generating a pressure differential of at least 100 PSI with said injected fluid between said first plurality of boreholes and said second plurality of boreholes; and

maintaining said pressure differential while driving said oil vertically toward said second plurality of boreholes.

6. A method as defined in claim 3, further comprising:

injecting a soaking fluid through said second plurality of boreholes and into said formation until said soaking fluid reaches one or more of said first plurality of boreholes and wherein; and

wherein the step of injecting said soaking fluid precedes injection of said displacing fluid.

7. A method of recovering oil from a subsurface earth formation, comprising:

establishing a shaft hole extending from the surface of the earth to said subsurface earth formation,

drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane at a first elevation in a lower portion of said formation,

drilling a second plurality of boreholes from the surface of the earth into said formation and terminating at a substantially uniform second elevation in an upper portion of said formation;

introducing a displacing fluid comprising substantially steam through said second plurality of boreholes and into said formation for forming a substantially horizontal blanket of introduced fluid at said second elevation;

injecting a driving fluid through said second plurality of boreholes and into said formation for driving said oil vertically toward said first plurality of boreholes; and

recovering said oil from said first plurality of boreholes while injecting said driving fluid into said formation.

8. A method as defined in claim 7, wherein said driving fluid comprises substantially a non-condensible gas.

9. A method as defined in claim 7, further comprising:

monitoring recovery of said driving fluid from each of said first plurality of boreholes; and

injecting a liquid comprising substantially water through selected ones of said first plurality of boreholes in response to recovery of said driving fluid from each of said first plurality of boreholes for inhibiting further recovery of said driving fluid.

10. A method as defined in claim 7, further comprising;

thereafter injecting another driving fluid through said first plurality of boreholes and into said formation for driving said oil vertically toward said second plurality of boreholes; and

recovering oil from said second plurality of boreholes while injecting said another driving fluid into said formation.

11. A method as defined in claim 7, further comprising:

prior to the step of injecting said displacing fluid, injecting a soaking fluid through said first plurality of boreholes and into said formation until said soaking fluid reaches one or more of said second plurality of boreholes; and

wherein the step of injecting said driving fluid through said second plurality of boreholes and into said formation comprises:

generating a pressure differential of at least 100 psi with said injected driving fluid within said formation between said first plurality of boreholes and said second plurality of boreholes; and

maintaining said pressure differential while driving said oil toward said first plurality of boreholes.

12. A method of recovering oil from a subsurface earth formation, comprising:

establishing a shaft hole extending from the surface of the earth to said subsurface earth formation;

drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane at a first elevation in an upper portion of said formation;

drilling a second plurality of boreholes from the surface of the earth into said formation and terminating at a substantially uniform second elevation in a lower portion of said formation;

introducing a displacing fluid comprising substantially steam through said second plurality of boreholes and into said formation for forming a substantially horizontally blanket of introduced fluid at said second elevation;

injecting a driving fluid through said second plurality of boreholes and into said formation for driving said oil vertically towards said first plurality of boreholes; and

recovering said oil from said first plurality of boreholes while injecting said driving fluid into said formation.

13. A method as defined in claim 12, further comprising:

monitoring recovery of said driving fluid from each of said first plurality of boreholes; and

injecting a liquid comprising substantially water through selected ones of said first plurality of boreholes in response to recovery of said driving fluid from each of said first plurality of boreholes for inhibiting further recovery of said driving fluid.

14. A method of recovering oil from a subsurface earth formation, comprising:

establishing a shaft hole extending from the surface of the earth to said subsurface earth formation;

drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane at a first elevation in a lower portion of said formation;

drilling a second plurality of boreholes from the surface of the earth into said formation and terminating at a substantially uniform second elevation in the lower portion of said formation;

introducing a displacing fluid comprising substantially steam through said second plurality of boreholes and into said formation for forming a substantially horizontal blanket of introduced fluid;

injecting a driving fluid through said second plurality of boreholes and into said formation for driving said oil vertically toward said first plurality of boreholes; and

recovering said oil from said first plurality of boreholes while injecting said driving fluid into said formation.

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(54) THERMAL RECOVERY OF VISCOUS HYDROCARBONS USING ARRAYS OF RADIALLY SPACED HORIZONTAL WELLS

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THERMAL RECOVERY OF VISCOUS HYDROCARBONS USING ARRAYS OF RADIALLY SPACED HORIZONTAL WELLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a process and apparatus for extracting mineral values from the earth. More specifically, this invention relates to a method and well system for recovering viscous hydrocarbons such as bitumen from a subterranean reservoir by injecting a heated fluid into the reservoir via an array of radially spaced horizontal wells.

2. Description of the Prior Art

In many areas of the world, there are large deposits of viscous petroleum, such as the Athabasca and Cold Lake Regions in Alberta, the Jobo Region in Venezuela and the Edna and Sisquoc Regions in California. These deposits are often referred to as "tar sand" or "heavy oil" deposits due to the high viscosity of the hydrocarbons which they contain. The distinction between tar sands and heavy oil is not settled. For both, however, normal reservoir flow rates are low, and techniques to improve flow are generally applicable to either without substantial changes including the present invention. Tar sand formations may extend for many miles and occur in varying thicknesses of up to more than 300 feet. These deposits may lie at or near the earth's surface or may be located under an overburden thousands of feet thick. However, tar sands not directly accessible from the surface consititute some of the world's largest presently known petroleum deposits. The tar sands contain a viscous hydrocarbon material, commonly referred to as bitumen, in an amount which ranges up to about 20% by weight. Bitumen is normally immobile at typical reservoir temperatures. For example, in the Cold Lake Region of Alberta, at a typical reservoir temperature of about 55°F, bitumen or heavy oil is immobile with a viscosity of about one thousand poise. However, at higher temperatures such as temperatures exceeding 200°F, the bitumen generally becomes mobile with a viscosity of less than 200 centipoise.

Since most heavy oil deposits are too deep to be mined economically, various in situ recovery processes have been proposed for separating the viscous oil from the sand in the formation itself and producing the oil through a well drilled into the deposit. Among the various methods for in situ recovery of bitumen from tar sands, processes which involve the injection of steam are generally regarded as the most economical and efficient. Steam can be utilized to heat and fluidize the immobile bitumen and, in some cases, to drive the immobilized bitumen toward production means.

The most common and proven method for recovering viscous hydrocarbons is by using steam stimulation techniques, an example being the "huff and puff" process. In this type of process, steam is injected into a formation by means of a well (the well is then sometimes shut-in to permit the steam to heat the bitumen), thereby reducing the viscosity of the crude oil. Subsequently, all formation fluids, including bitumen of reduced viscosity, water and steam, are produced from the same well using accumulated reservoir pressure as the driving force for production. Initially, sufficient pressure may be available in the vicinity of the wellbore to lift fluids to the surface; as the pressure falls, artificial lifting methods are normally employed. Production is terminated when the rate of oil production declines to an uneconomic rate. The cycle is then repeated until overall cycle economics are no longer attractive.

During the early cycles of steam injection and fluid production, oil production rates may be quite high since the oil nearest to the well is being produced. However, during subsequent steam cycles as the oil nearest the well is depleted, steam must move farther into the formation to contact the oil and as a result increased heat losses make the steam less effective as an oil recovery agent. The process looses efficiency with each cycle and eventually oil production becomes uneconomical.

Another general method for recovering viscous hydrocarbons is by using "thermal drive" processes. Such processes employ at least two wells, an injection well and a production well, spaced apart from each other by some distance and extending into the heavy oil formation. In operation, a heated fluid, usually steam or hot water, or a heat-generating fluid such as air, is injected through the injection well into the formation where it heats and drives fluids towards the production well. The dominant mechanisms for oil displacement are viscosity reduction of oil (as with steam stimulation), swelling and perhaps steam distillation, depending on the character of the oil. The principal advantage of using a thermal drive process is that higher overall recoveries can usually be obtained than with steam stimulation processes. For example, it has been the general experience in California that only relatively low recoveries are obtained overall by steam stimulation; on the other hand, while the recovery is higher with steam floods, more heat is used per barrel of oil produced.

One basic problem with thermal drive is that while the region of the reservoir which has been swept by the heated fluid or heat-generating fluid contains low residual oil saturations, generally less than half of the reservoir is swept before the flowing heated or heat-generating fluid breaks through at the production well. Once this occurs, fluid bypass tends to make further operations uneconomical. A great deal of work in the industry has been devoted to improving the fraction of the reservoir volume which can be swept by the thermal process before the heated or heat-generating fluid breaks through at the production well causing oil production to become uneconomic, i.e., improved sweep efficiencies are needed.

Many of the more promising approaches currently being developed utilize combinations of horizontal wells in order to improve oil recoveries. Such horizontal wells may also be combined with access shafts or very large-diameter boreholes capable of accommodating the passage of men and equipment.

One such process is described in U.S. Patent No. 4,020,901 which issued on May 3, 1977 to Peter Pisio and Charles F. Kirkvold (Chevron Research Company). This patent discloses a special arrangement of equipment for recovering heavy oil from very thick tar sand formations. The invention involves the use of heating conduits extending horizontally from a vertical shaft into the tar sand formation. Steam is flowed through the horizontal conduits to indirectly heat the adjacent formation and create a flowpath surrounding the conduits for production of fluids. In order to promote flow of heated petroleum to the flowpath, steam is injected directly into the formation via separate injection conduits. The patent discloses the use of a set of vertical injection conduits for delivering steam to the formation; alternatively, a set of slanted wells may be used to deliver the steam to the formation. In essence, the approach taken is to sweep the heated petroleum into a laterally extending flowpath and outwardly along the flowpath. The heated petroleum is then recovered near the end of the horizontal conduit and floats into the shaft. Presumably, over time, the steam will sweep more and more petroleum to the end of the horizontal conduit thereby creating an expanding steam saturated region.

One problem with the method of U.S. Patent No. 4,020,901 is that while the creation of a flowpath is highly desirable, the approach here will be inherently extremely slow since heat is delivered to the formation for this purpose only indirectly. Conductive heating by indirect heating of the formation adjacent the horizontal conduit will be slow. Also, the method does not utilize many of the advantages of steam stimulation, such as removal of near-wellbore damage caused by fine solids, and asphaltic paraffinic deposits. In addition, a hot path between the injection location and production location is needed to effect fluid communication; however, this hot path of very high mobility tends to cause hot injected fluid to bypass the cold, viscous oil which must be heated.

Another patent utilizing a mine shaft or other large-diameter access shaft is U.S. Patent No. 4,160,481 which issued on July 10, 1979 to L. J. Turk and R. O. Kehle (assignee: the HOP Corporation). Some popular accounts of this method have referred to it as the "Hotplate" process. This is because steam is injected into the formation via horizontal wells which extend from a central access shaft like spokes on a wheel. The steam penetrates into the formation upwardly due to gravity and heat is transferred to the viscous oil. Once heated, the oil begins to flow. Oil and water are produced back through the horizontal wells and pumped through the vertical access shaft for treatment. The patent also discloses that oil may be more effectively swept from the formation by simultaneously injecting steam via one or more of the horizontal wells and producing oil via one or more other horizontal wells. However, the technique is primarily a steam stimulation or steam soak technique.

While U.S. 4,160,481 represents an advancement in systematically heating a formation and recovering normally immobile heavy oil in an efficient manner, problems still exist in the sweep efficiency of the process. It is believed that substantial quantities of oil will remain between the radially extending horizontal wells. Therefore, there is a continuing need for an improved thermal process for the effective recovery of viscous hydrocarbons from subterranean formations such as tar sand deposits, especially a process having improved sweep efficiency.

SUMMARY OF THE INVENTION

In accordance with the present invention, an in-situ process and well geometry are provided for recovering normally immobile mineral values from a subterranean formation. An access shaft is formed in the formation and a first array of radially-spaced horizontal wells is drilled from the shaft into the formation. The first array of wells is completed so that upon the injection, via alternate wells, of a mobilizing fluid capable of causing the mineral values to flow, an outer zone of high fluid mobility is formed between the ends of the first array of wells. Then, a second array of horizontal wells is drilled, radially spaced between the first array and being substantially shorter than the first array. The mobilizing fluid is then injected into the formation via said first array of wells to mobilize and drive mineral values to the second array of wells, where such values can be recovered. By creating the outer ring of high fluid mobility and using the short horizontal wells, vastly improved sweep efficiencies are achieved.

The preferred embodiment is an improved in-situ thermal method and well geometry for recovering heavy oil or bitumen. The invention is a significant improvement over the process described in U.S. Patent No. 4,160,481. The preferred embodiment comprises the following steps: (1) forming a large diameter access shaft in a subterranean bituminous formation; (2) drilling a first set of radially-spaced, substantially horizontal wells out from the access shaft; (3) completing each horizontal well over most of its length such that fluid communication exists with the formation; (4) injecting a heated or heat-generating fluid into the first set of wells and into the formation, and allowing the formation to soak; (5) producing oil from the first set of horizontal wells until production is no longer efficient; (6) repeating the fluid injection, soak and production cycle until oil production is no longer efficient; (7) cementing a liner in or otherwise plugging each horizontal well over a majority of its length to prevent fluid communication with the formation over the plugged portion, while leaving an end portion of each well in fluid communication with the formation; (8) injecting heated or heat-generating fluid into alternate wells of the first set of wells to displace oil to the remaining horizontal wells to create a path of thermal communication between the ends of the first set of wells (a heated annular zone of high fluid mobility); (9) drilling a second set of horizontal wells which are radially spaced between the first set and which are substantially shorter than the first set of wells; (10) injecting the heated or heat-generating fluid into the first set of wells to displace and force hydrocarbons to the second set of short horizontal wells, and producing oil from the second set of wells. Vastly improved sweep efficiency and oil recoveries can be achieved using this invention.

The "soak" period mentioned in steps (4) and (6) may be as short as the time it takes to turn the wells around following injection of heated or heat-generating fluid (i.e. without shutting in), or the wells may be physically shut-in depending on the type of oil and reservoir characteristics. In addition, it will be preferred for very viscous oils (e.g., Cold Lake, Alberta) to inject steam during the stimulation steps (4) and (6) at above formation fracture pressures. Then during the thermal drive stage steps (8) and (10), steam will preferably be injected at below fracture pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURES 1(a) and 1(b) taken together schematically illustrate a well array for practicing the method of U.S. Patent No. 4,160,481.

FIGURES 2(a) through 2(d) taken together schematically illustrate the method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a thermal recovery process utilizing a special well geometry to provide significantly improved sweep efficiencies over the well geometry and process of U.S. 4,160,481. The invention is preferably applied in recovering normally immobile carbonaceous material from a subterranean formation by heating it with a heated or heat-generating fluid, although other applications where improved sweep efficiency is a requirement will be apparent to those skilled in the art. Such applications would include the leaching of uranium or other minerals in situ. The preferred method involves the steam stimulation of a reservoir utilizing a set of radially spaced long horizontal wells, completing this set of wells so that subsequent steam flooding can be performed to create an outer annular thermal communication zone surrounding the radially-spaced long horizontal wells, drilling another set of short horizontal wells in between the initially drilled wells, and injecting steam into the formation so that oil is swept to the short wells. Preferably, both sets of horizontal wells are completed so that the reservoir volume adjacent to the access shaft remains cool. Optionally, the short wells may be ultimately recompleted so as to sweep oil from the reservoir region immediately adjacent to the access shaft. By practicing this invention, substantial additional quantities of oil are swept from the reservoir.

The following description will disclose an especially preferred embodiment, involving the use of steam to heat and mobilize viscous crude. However, it should be understood that the method and geometry of the present invention should not be so limited and includes the use of other heated fluids (eg. hot water, solvent vapors, etc.) or heat-generating fluids (eg. air) which can be employed to reduce the viscosity of the heavy oil. It will be apparent to those skilled in the art which fluids will be most appropriate; this selection will depend in particular upon the reservoir characteristics, crude oil characteristics, availability of the particular fluid, and so forth. It can be noted with respect to the use of a heat-generating fluid, however, that the complete combustion of oil in the area covered by the horizontal wells is not necessary. Rather, only such amounts of the heat-generating fluid as are necessary to cause the viscous crude oil to flow will usually be injected.

As mentioned, this invention is a significant improvement over the method of U.S. Patent No. 4,160,481. The method of this patent may be better understood by referring to FIGURES 1(a) and 1(b). A substantially large diameter vertical access shaft 3 penetrates subterranean heavy oil formation 4. The access shaft 3 is provided with a larger work chamber 5 at its lower end and also a sump hole 7 beneath the chamber 5. The access shaft 3 and work chamber 5 are sized and provided with appropriate equipment so that workmen are able to descend therein to perform necessary tasks. A plurality of horizontal wells 6 are then drilled into the formation 4. These wells are radially spaced from each other, as particularly illustrated schematically by FIGURE 1(b). A relatively short portion of each well 6 will be provided with casing 8 while the remaining portion of each well 6 will be lined with a perforated drain pipe or screened liner 9. Typical lengths of the wells 6 will range from approximately 500 to 2000 feet long. Steam is injected into the formation via the wells 6 and allowed to heat the oil. Heated fluids, including crude oil, are recovered via the wells 6. This steam stimulation cycle is repeated until oil production declines to uneconomic levels.

According to the method of U.S. Patent No. 4,160,481, the radial wells may be used in a thermal drive or steam flooding mode, without modifying the wells or manner of injection in any manner. Unfortunately, while improved oil recoveries are possible, sweep efficiencies will still not be satisfactory. For example, it is predicted that only from about 10% to about 50% of the potential oil recovery will be achieved in the region containing the radial wells 6 due to poor sweep. Much of the remaining oil lies in-between the radial wells 6.

The present invention involves a unique combination of proper completion techniques, improved flooding with a heated or heat-generating fluid and the drilling of additional short wells in order to significantly improve sweep and recovery efficiency. In addition, the method provides for safe operating conditions for the workmen located in the cavern 5.

FIGURE 2 illustrates the sequence of steps in achieving these benefits. Again, the following description will focus on the recovery of heavy oil using steam as a heated fluid, but the invention is not limited to the use of steam (or heavy oil for that matter). The method of U.S. Patent No. 4,160,481 is initially applied and is represented by FIGURE 2(a). The double arrows indicate that steam is initially injected and mobilized fluids produced through all radial wells 6; that is, a steam stimulation process is applied. Wells 6 are conventionally completed, being in fluid communication with the formation over most of their length. For example, a liner slotted over most of its length may be installed in each well using well-known techniques.

It should be noted that, for heavy oil or tar sand formations, it is especially preferred to inject steam at above formation fracture pressures during the stimulation process. For example, it has been discovered that in certain formations, unless steam is injected at above fracture pressure, the stimulation process is too slow to be considered economic at current world oil prices.

After a number of steam stimulation cycles, frequently 5 to 10, oil production per barrel of steam will decline and the oil/steam ratio for the last cycle will become relatively unattractive economically. To obtain the remaining recoverable oil, which may be as high as 50 to 90 percent of that originally present in the region of the deposit containing the horizontal wells 6, a steam flooding displacement must be performed. However, because of steam bypass it will not be possible to simply utilize the well configuration of FIGURES 1(a) and (b) wherein the steam is introduced over substantially the entire length of each well 6. The geometry of the system shown in FIGURES 1(a) and (b) is such that steam will flow into and oil will be displaced from only a narrow path between the perforations immediately next to the end of adjacent casings 8. The bulk of the oil remaining between adjacent wells 6 following steam stimulation will therefore not be recovered by steam drive due to the steam short circuit.

In practicing this invention in heavy oil or tar sand formations, above fracture steam stimulation is continued until a minimum degree of oil mobility is created in the formation. In other words, the formation will be heated sufficiently so that a steam displacement process can be performed at a reasonable rate below fracture pressure. Then, with reference to FIGURE 2(b) in particular, each radial well 6 is recompleted so as to prevent fluid communication with the deposit 4 over a majority of its length, and preferably over about 60 to about 95 percent of its length (i.e., 5-40% will communicate with the formation). This may involve squeezing cement into the liner or casing openings, or otherwise plugging some of the openings. The double-lined portions of each well in FIGURES 2(a)-2(d), for example length "L" of FIGURE 2(b), represent the portion of each well which has been prevented from communicating with the formation. Alternate horizontal wells 6 are then utilized as injection wells and production wells, as represented schematically by FIGURE 2(b). Steam at below formation fracturing pressure is then injected into the injection wells 6' to displace fluids (both oil and water), which are produced from the production wells 6''. Steam injection and fluid production are continued until thermal communication is established between alternate wells, i.e. a path of high fluid mobility is established between the ends of the injection wells 6' and production wells 6''. As may be seen in FIGURE 2(b), an outer heated zone of high oil mobility is created in the deposit 4. The creation of this high mobility zone is one critical feature of this invention. This permits later operation without substantial steam bypass and results in significantly improved sweep efficiencies.

The next step in practicing this invention is to drill a second set of nearly horizontal wells 12 between the original set. These wells must be substantially shorter than the initial set of wells, preferably as short as possible. Thus, if wells 6 were approximately 500-2000 feet long, the short wells 12 might be drilled out to a distance of from about 35 feet to about 200 feet. These short wells 12 are completed, as with wells 6, such that the portions of the short wells 12 adjacent to the cavern 5 are not permitted to fluidly communicate with the deposit 4. The length which is in fluid communication (eg. perforated section of a casing) is determined so as to provide a reasonable production rate, while the unperforated section will have a length consistent with a comfortable working environment in the cavern 5. For example, good working numbers for many formations for the unperforated length would be about 25-50 feet, with 10-150 foot perforated outer portion. Note that while reference is made to a perforated portion, this should not be construed as limiting; a screened or slotted liner may be used over this length, or other manner of creating fluid communication between a portion of the well and the formation. The length of the perforated portion will be determined by the desired production rate and will be consistent with avoiding excessive rates of sand production. That is, a long enough perforated length will be used to handle the anticipated flow rate, but no longer than necessary for this purpose. It should also be noted that the short wells 12 may be drilled and completed at the same time as wells 6, so long as they are prevented from communicating with the formation until the thermal drive step is ready to be accomplished. This may be done, for example, by casing the short wells, but not perforating the wells.

The original horizontal wells 6 are then converted to injection wells. Steam is injected through all original wells 6 at below fracture pressures and reservoir fluids are displaced toward the new short wells 12. This is schematically illustrated by FIGURE 2(c).

With reference to FIGURE 2(d), a final optional procedure will be preferred when significant quantities of oil remain adjacent to the cavern 5. The outer portion of each short production well 12 in communication with the deposit is plugged with suitable material, such as cement, and the portion of each well 12 which is adjacent to the cavity is recompleted so as to be in fluid communication with the deposit. Again, this may involve perforating this portion, or otherwise forming an opening in the casing or liner of wells 12. Residual steam pressure in the formation will then further displace oil into wells 12 for recovery.

A major purpose of leaving an unperforated zone in the short wells adjacent to the cavern 5 until just before abandonment is to provide an insulating volume in the formation surrounding the cavern 5 as a heat shield. The size of the desirable heat shield will depend on formation temperature, steam temperature, allowable cavity temperature, cavity cooling installed, and the time of operation. Generally from about 25 to about 100 feet will be suitable depending also of course on the total length of the short well.

Further details on drilling and completing horizontal wells may be found in G. E. Bezaire and I. A. Markiw, "Esso Resources Horizontal Hole Project at Cold Lake", Paper No. 79-3010, presented at the 30th Annual Technical Meeting of the Petroleum Society of CIM, May 8-11, 1979.

Finally, it may be noted that the precise quantities of steam (or other heated or heat-generating fluid) to be injected cannot be determined without knowing details of a particular reservoir; however, one skilled in the art can easily determine these quantities. For the preferred process utilizing steam, for example, the stimulation steps may utilize a total volume per well of from perhaps 20,000 to 400,000 bbls of steam having a 50%-100% quality at 150 to 2000 psi. When injecting steam at above fracture pressures, as is especially preferred for many heavy oil or tar sand reservoirs, the primary reservoir characteristic determining steam quantities will be the reservoir thickness. The steam drive steps may use a similar quality steam at below fracture pressures in amounts ranging from perhaps 0.5 to 1.5 pore volumes of the reservoir volume to be swept. These specific numbers are not intended to be limiting, however, but illustrative.

It should also be apparent to those skilled in the art that generally the horizontal wells will be located near the bottom of a given reservoir; however, this will of course depend on vertical permeabilities and the presence of horizontal low permeability regions, etc. Further, the expression "horizontal wells" will include wells having a slightly downward or upward slope in order to facilitate production of fluids.

While the foregoing discussion has been devoted to a description of a well geometry utilizing a 360° radial array of horizontal wells whose ends roughly define a circle, it should be apparent that the invention could be practiced with fewer wells whose ends need not define a circle. Such an arrangement might be appropriate, for example, for an access shaft located near the outer boundary of a given formation. This arrangement could consist of two long radially-spaced horizontal wells in combination with a single short horizontal well in between. A mobilizing fluid is injected into one long well to create a path of high fluid mobility between the ends thereof. Then, the mobilizing fluid is injected into both long wells to mobilize and drive mineral values located between the two long wells to the short well for recovery. Note that the two long wells and the short well will be geometrically arranged to provide a sufficient distance between the end of the short well and the high mobility path so that the mobilizing fluid can sweep a substantial portion of the mineral values located between the long wells before breaking through to the short well, i.e., to give good sweep efficiency. This distance is inherently sufficient with a radial array of wells as shown in Figure 2. For most applications, a greater number of wells will be preferred in order to achieve the best sweep efficiency and good economics.

In consequence of practicing this invention, significantly higher displacement and oil recovery efficiencies are obtained. The cavity or cavern 5 is shielded to a maximum extent from the high injection pressures desirable during the steam flooding of the deposit 4. The method of this invention provides a significant improvement over the process of U.S. Patent No. 4,160,481.

Various modifications and alterations in the practice of this invention and in particular in the heated or heat-generating fluid to be used should be apparent to those skilled in the art without departing from the scope and spirit of this invention. It should be understood that the invention claimed here should not be unduly limited to the specific example or embodiment set forth herein.

Having described my invention in detail, what I claim is:

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for recovering normally immobile mineral values from a subterranean formation, the method comprising:

(a) penetrating said formation with an access shaft;

(b) extending first and second radially-spaced substantially horizontal wells from said shaft into said formation;

(c) extending a third substantially horizontal well from said shaft into said formation, said third well being located between said first and second wells and being substantially shorter than either of said first and second wells;

(d) injecting a mobilizing fluid into said first well and recovering mobilized mineral values via said second well so that a path of high fluid mobility is created in said formation between the ends of said first and second wells;

(e) injecting said mobilizing fluid into said first and second wells to further mobilize and drive mineral values through said formation to said third well, the end of said third well being located a sufficient distance from said high mobility path to provide for good sweep efficiency of the mineral values located between said first and second wells; and

(f) recovering said mobilized mineral values via said third well.

2. The process of claim 1 wherein said mineral values are heavy oil or bitumen.

3. The process of claim 2 wherein said mobilizing fluid is a heated or heat-generating fluid.

4. The process of claim 2 wherein said mobilizing fluid is steam.

5. The process of claim 2 wherein said mobilizing fluid is an oxygen-containing gas.

6. A process for recovering normally immobile mineral values from a subterranean formation, the process which comprises the steps of:

(a) sinking an access shaft into said formation;
(b) penetrating said formation from said shaft with a first array of radially-spaced horizontal wells, the outer ends of these wells defining an annular zone around said shaft;
(c) completing said first array of wells so that the outer ends of these wells are in fluid communication with said formation;
(d) injecting a mobilizing fluid through alternate wells of said first array, until a high fluid mobility is created in said annular zone;
(e) penetrating said formation with a second array of horizontal wells, radially-spaced between said first array of wells, said second array of wells being substantially shorter than said first array of wells;
(f) injecting said mobilizing fluid into said formation via said first array of wells to drive mobilized mineral values to said second array of wells; and
(g) recovering said mobilized mineral values via said second array of wells.

7. The process of claim 6 wherein each of said first array of wells ranges from about 500 to about 2000 feet long and each of said second array of wells ranges from about 35 feet to about 200 feet long.

8. A thermal process for recovering normally immobile carbonaceous materials from a subterranean formation which comprises:

(a) penetrating said formation with a generally vertical access shaft having a work chamber at its lower end;

(b) extending a first plurality of wells laterally and radially outward from said chamber into said formation;

(c) injecting a heated or heat-generating fluid into said formation via said first plurality of wells to heat and fluidize a portion of said carbonaceous materials:

(d) producing said fluidized carbonaceous materials via said first plurality of wells;

(e) completing each of said first plurality of wells so as to be in fluid communication with said formation over only an outer portion thereof;

(f) injecting said heated or heat-generating fluid into and recovering fluidized carbon materials from alternate wells of said first plurality of wells to create an outer zone of high fluid mobility around said first plurality of wells;

(g) extending a second plurality of wells in fluid communication with said formation laterally and radially outward from said chamber into said formation, said second plurality of wells being substantially shorter than said first plurality of wells and spaced between said first plurality of wells;

(g) injecting said heated or heat-generating fluid into said high mobility zone via said first plurality of wells to sweep fluidized carbonaceous materials from said formation to said second plurality of wells; and

(i) recovering fluidized carbonaceous materials from said second plurality of wells.

9. The method of claim 8 wherein said heated or heat-generating fluid is steam.

10. The method of claim 9 wherein steam is injected in step (c) at a pressure above formation fracture pressure.

11. A method for recovering viscous hydrocarbons from a subterranean deposit penetrated by an access shaft which comprises:

(a) drilling a first plurality of substantially horizontal, radially-spaced wells from said shaft into said deposit;

(b) completing said first plurality of wells so that each well is in fluid communication with said deposit over substantially its entire length;

(c) injecting a heated or heat-generating fluid into said deposit via said first plurality of wells to heat said viscous hydrocarbons, and thereafter producing via said first plurality of wells mobilized fluids, including heated viscous hydrocarbons, from said deposit;

(d) recompleting said first plurality of wells so that each recompleted well is in fluid communication with said deposit over less than a majority of its length;

(e) injecting said heated or heat-generating fluid into said deposit and producing heated fluids from said deposit via alternate recompleted wells so that a path of thermal communication is established between said recompleted wells;

(f) drilling a second plurality of substantially horizontal wells from said shaft into said deposit, each of said second plurality of wells being radially spaced between alternate recompleted wells and being substantially shorter than any of said recompleted wells;

(g) completing said second plurality of wells so that each is in fluid communication over an outer portion of its length; and

(h) injecting said heated or heat-generating fluid into said first plurality of wells to drive mobilized fluids in said deposit, including heated viscous hydrocarbons, to said second plurality of wells for recovery.

12. The method of claim 11 wherein said first and second pluralities of wells are completed in steps (b), (d), and (g) such that the region of said deposit which surrounds the lower portion of said access shaft from which said wells are drilled remains relatively cool.

13. The method of claim 11 wherein said heated or heat-generating fluid is steam.

14. The method of claim 11 wherein steam is injected in step (c) at a pressure above formation fracture pressure.

15. The method of claim 11 which includes performing step (f) along with performing step (e) and preventing said second plurality of wells from being in fluid communication with said deposit until step (g) is reached.

16. The method of claim 11 which further includes:

(i) recompleting said second plurality of wells such that fluid communication with said deposit is prevented where communication was previously permitted by the completion of step (g) and such that fluid communication with said deposit is permitted where previously prevented; and

(j) producing heated fluids from said deposit via said second plurality of recompleted wells.

17. The method of claim 11 wherein each of said second plurality of wells is from about 35 feet to about 200 feet long, said outer portion is from about 10 feet to about 150 feet long, and the length of said first plurality of wells ranges from about 300 to about 3000 feet.

18. The method of claim 11 wherein each of said first plurality of wells is recompleted in step (d) so as to be in fluid communication with said formation over about 5 to about 40 percent of its length.

19. A system of wells for use in the in-situ recovery of mineral values from a subterranean formation comprising:

(a) an access shaft penetrating said formation;

(b) a first array of long, radially-spaced horizontal wells extending outwardly from said shaft into said formation;

(c) means for completing said first array of wells such that each well is in fluid communication with said formation only over an outer portion thereof, whereby a zone of high fluid mobility is created between said outer portions upon injection of a mobilizing fluid into and recovery of mineral values from said formation via alternate wells of said first array;

(d) a second array of horizontal wells radially spaced uniformly between said first array of wells, said second array of wells being substantially shorter than said first array of wells;

(e) means for completing said second array of wells such that each is in fluid communication with said formation, whereby a substantial portion of the mineral values contained between said high mobility zone and said second array of wells are swept to said second array of wells upon injection of said mobilizing fluid into said formation via said first array of wells.

20. The system of claim 19 wherein each of said first array of wells ranges from about 500 to about 2000 feet long and each of said second array of wells ranged from about 25 feet to about 200 feet long.

21. The system of claim 19 wherein each of said first array of wells is in fluid communication with said formation over about 5 to about 40 percent of its length.

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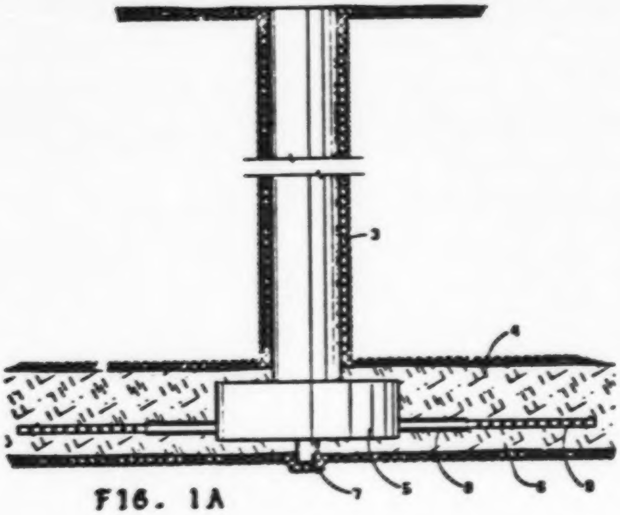

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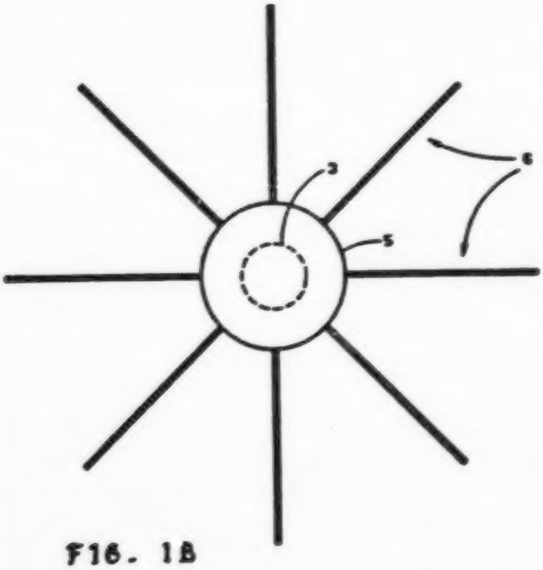

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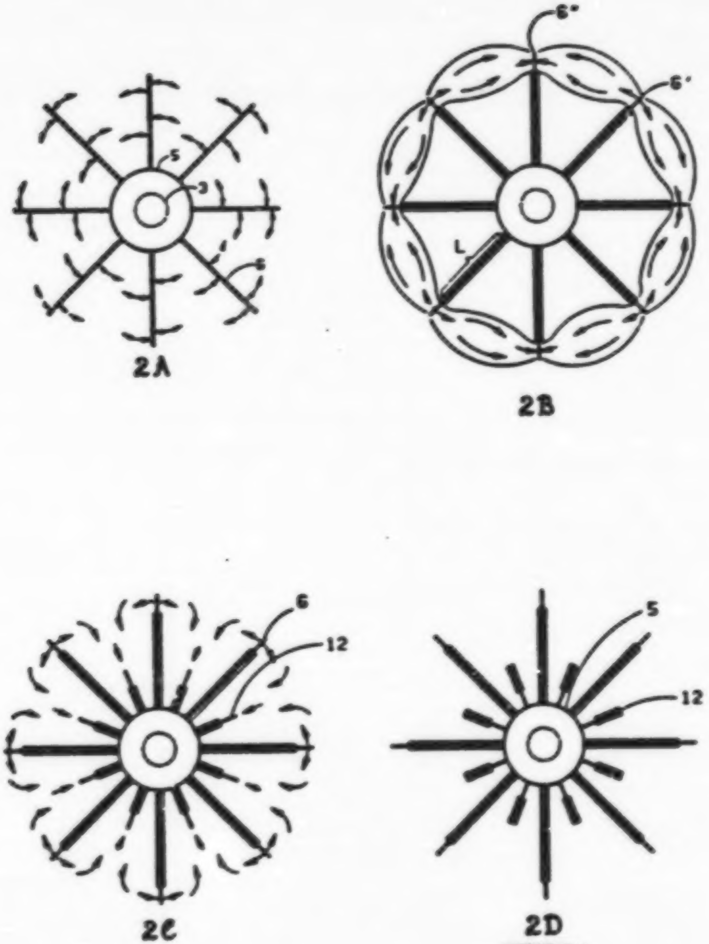
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FIG. 2

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